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IR GEORGE NELSON, Bt, President of the Institution of Electrical Engineers, in the Chair

The following Paper was presented for discussion and, on the motion of the hairman, the thanks of the Joint Meeting were accorded to the Authors.

Paper No. 6133

# THE PIMLICO DISTRICT HEATING UNDERTAKING—COSTS AND FINANCIAL RESULTS

by

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SYNOPSIS

The Paper gives the costs of construction and the financial results obtained in operation f the Pimlico District Heating Undertaking. The installation was described in a revious Paper[1] and estimated costs only were given. The financial results in the present aper are based on experience in actual operation of the undertaking in the year ending ) September, 1953, as being the only year to date with a constant number of premises applied with heat. The costing of the undertaking is complicated by the widely iffering dates of installing the plant concerned and the sharing of ownership of the stallation between two authorities—the supplier of the heat and the purchaser. This oint is discussed at length and the method of allocation of costs is described in detail.

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[1] Bryan Donkin, A. E. Margolis, and C. G. Carrothers, "The Pimlico District Heating ndertaking." Proc. Instn Civ. Engrs, Pt I, vol. 3, p. 259 (May 1954).

For convenience of reference the Paper contains a brief summary of the main particulars given in the previous Paper, and a simplified diagram of the heat supply and distribution is included.

It is concluded that the estimated financial results of operation are close to those obtained in practice and that an improved thermodynamic cycle of combined heat-electric generation would effect an appreciable reduction in the net cost of heat. It is finally pointed out that the effective use of the economies of combined heat-electric generation depends on the development of efficient and inexpensive methods of heat distribution and the existence of reasonably concentrated demands for heat.

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## Introduction

The Pimlico District Heating Undertaking was the subject of a previous Paper[1] which described the layout and construction of the heating system, and the housing estates and associated premises which it serves. Detailed information was given of the actual heat output and the electricity metered in the years ended 30 September, 1952, and 30 September, 1953. The economy of district heating was discussed in general terms and the conclusions reached were based on the known costs of plant of similar and well-established types used for electrical supply and in central heating installations.

This Paper gives particulars of the capital cost of the Undertaking and the annual costs of operation together with additional information of heat quantities and other technical particulars. It is written as a sequel to the original Paper from which relevant items of information are extracted and are as follows :—

*Combined heat-electric generating plant at Battersea "A" power station*

| | |
|---|---|
| Two machines each of continuous maximum output | 1,350 kW |
| Exhaust heat, per machine | 227·5 therms/hour |
| Voltage of electrical output | 3,300 V |
| Temperature of heat output | 200°F |
| Initial steam pressure | 600 lb/sq. in. gauge |
| Initial steam temperature | 800°F |
| Back pressure of exhaust steam | 2 lb/sq.in. gauge |
| Turbine speed | 10,000 r.p.m. |
| Alternator speed | 1,500 r.p.m. |

*Heat-storage accumulator at Pimlico*

| | |
|---|---|
| Inside diameter | 29 ft |
| Height | 126 ft |
| Volume | 80,000 cu. ft |
| Effective heat storage for 80°F rise | 4,000 therms |
| Heat storage per cu. ft. | 5,000 B.t.u. |

## Costing periods

When the investigation of the overall cost of providing district heating was put in hand it was decided to investigate first the costs during the year ended 30 September, 1953, because that was the only year throughout which heat was supplied to a constant number of premises. By that year, moreover, the heat load had developed to a considerable extent and amounted to more than half the estimated ultimate load. For reasons that are explained later the figures for any other year are less reliable and useful in investigating distribution costs but the expenses in the year ended 30 September, 1954, are also given.

In the years ended 30 September, 1953, and 30 September, 1954, the Undertaking was carrying nearly the full annual charges on the ultimate capacity of heat supply plant at Battersea, on transmission mains between Battersea and Pimlico, and on heat storage, but these works were only partly loaded. The Undertaking will not be working with full efficiency and economy until all the housing it was designed to supply has been completed and become occupied. An estimate of the overall costs when the Undertaking is fully developed is included.

## General description

In order to clarify the financial considerations which follow a short outline of the main features of the scheme is given.

Fig. 1 shows a simplified flow diagram of the system. The source of heat is exhaust steam from two back-pressure turbo-alternators specially installed for this purpose at Battersea power station and now operating under the Central Electricity Authority. The electrical output of the back-pressure machines is delivered to the bus-bars supplying power to the station auxiliaries. The steam to the back-pressure turbines is supplied by boilers installed for an entirely different purpose many years before the district-heating supply was ever considered. It is to this circumstance that the valuation of the service given by the combined heat-electric plant at Battersea owes its complication.

The exhaust steam is used to heat water which is circulated through the pipework of the district-heating system by way of a tunnel belonging to the Metropolitan Water Board under the Thames. The added heat content of the water as it leaves Battersea is metered at the station. From this point the heat is purchased from the C.E.A. by the Westminster City Council.

The Authority provided the installations within its own boundaries and the Council provided all the installations outside these boundaries other than the tunnel under the Thames, for the use of which a nominal rent is paid.

After transmission under the Thames the heat delivered is again measured, by meters belonging to the Council at a control station on the Pimlico Churchill Gardens Housing Estate where there is a heat accumulator and a pump-house. From this point the hot water is circulated by electric-motor-driven pumps to the three main consumers, Churchill Gardens including Russell House, Abbots Manor Housing Estates, and a block of privately owned flats known as Dolphin Square.

## Costing of heat supplies

The costing of district-heating supplies derived from back-pressure or pass-out turbines in combined heat-electric generating stations has received much consideration on the Continent. In Germany, for instance, it was stated[2] some time ago that more than sixty different methods of cost allocation between electricity and heat supply were available and that more were being evolved each year. The heat supplies in Germany are derived from a large number of independent sources, mainly power-company-owned generating stations, and each heat-producing undertaking tends to evolve its own method of costing to suit its particular circumstances.

If, however, it is desired to assess the true net additional cost incurred by an electricity generating undertaking in providing a district-heating supply by combined heat-electric generation the Authors consider that this can be done only by

[2] M. Stegeman, "*Gesamtplanung von Heizkraftanlagen.*" *Elekt. wirts.*, vol. 53, p. 410 (Aug. 1954).

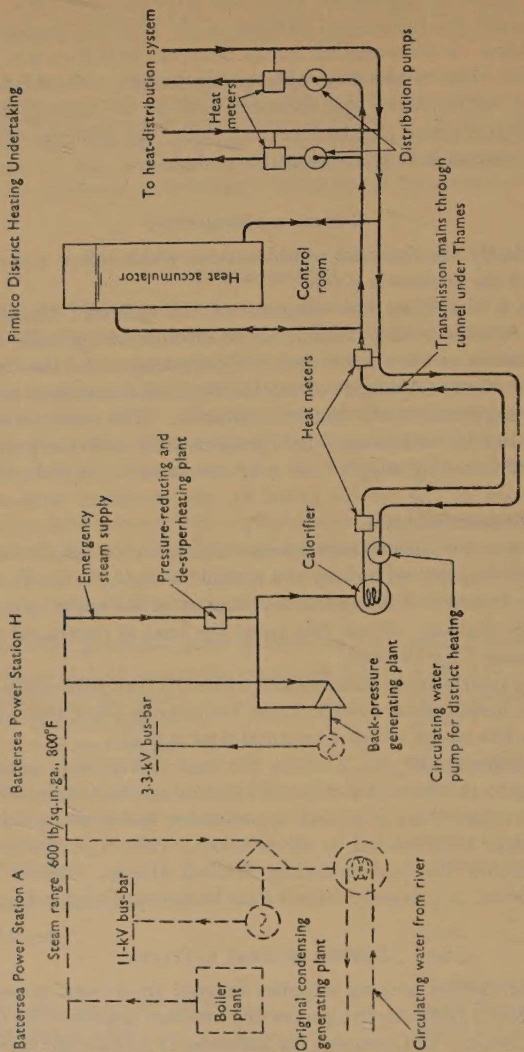


FIG. 1.—SIMPLIFIED DIAGRAM OF HEAT SUPPLY AND DISTRIBUTION

comparing the overall costs incurred on combined heat-electric generation with the estimated costs which would be incurred on electricity generation without the heat supply. In an expanding, fully integrated, and predominantly steam-generating system a planned capacity of generating plant has to be installed each year and the alternative to the installation of back-pressure or pass-out plant on a large scale would be the installation of condensing plant having the same reliable output capacity. (Such plant would not or might not, however, be installed in the same locations as the combined heat-electric plant.) In the case of the Central Electricity Authority's system, therefore, the net additional cost of providing heat supplies on

large scale can be assessed by deducting from the overall cost of combined heat-electric generation the estimated cost which would be incurred, in the absence of the heat supplies, in producing from condensing plant installed at the same time as the combined heat-electric plant, the same electrical output as obtained from the latter plant.

The foregoing method has the drawback that it involves arbitrary assumptions regarding the location and cost of production of hypothetical condensing plant but in the circumstances of the Authority's system it appears to be the only logical method. As mentioned the figure arrived at is the net additional, or marginal, cost of providing the heat supplies and the whole benefit of the fuel economy from combined heat-electric generation is given to the heat supplies and none to electricity supply. If heat is to be made available at a competitive price, supplies must get a share of the benefit that will compensate for the additional overhead charges involved in district heating compared with independent central heating. If that is possible, however, without absorbing the whole benefit of the economy, it appears that the price to be charged for heat should be determined in a way resulting in the remaining benefit being shared between electricity and heat supply. That, however, is a matter of policy not pursued in this Paper.

In the case of the Pimlico Undertaking the capacity of the back-pressure sets at Battersea is so small in relation to the capacity of even one modern condensing set that their installation could not have influenced the Authority's programme for installing condensing plant. Moreover, no additional boiler plant was provided at Battersea "A" for heat supply and the back-pressure sets receive their steam from boilers installed before the war. Owing to the limited capacity of that boiler plant the installation of the back-pressure sets did not increase the reliable electrical output capacity of Battersea "A." In these circumstances the cost of providing the heat supply to the Council is assessed by determining the cost of combined heat-electric generation at Battersea and deducting, not the total estimated cost of producing the electrical output of the back-pressure sets from condensing plant installed at the same time as those sets, but only the estimated running cost of such plant. In other words, the electrical output of the back-pressure sets can be credited with no capacity value and is valued at the running cost of condensing generation. In assessing that cost it has been assumed arbitrarily that, in the absence of the heat supply to the Council, the kilowatt-hours supplied from the back-pressure sets at Battersea would have been produced by condensing plant operating at an efficiency of 27% with fuel of the same price and calorific value as that used at Battersea "A."

### Capital cost of plant installed at Battersea Power Station to supply heat to the Council

The capital cost of the plant installed for the specific purpose of the heat supply (including an allowance of 10% for engineering and administrative expenses and capitalized interest) was as follows:—

*Commissioned in* 1951

| | |
|---|---|
| Two 1,350 kW back-pressure turbo-alternators, two heat exchangers, two emergency steam-pressure and temperature-reducing equipments, two circulating-water pumps, pipework, instruments, meters, and ancillary equipment . . . . . . . . . . . . . . . . . | £111,651 |

*Commissioned in* 1954

| | |
|---|---|
| One heat exchanger . . . . . . . . . . . . . . . . . . . . | £12,100 |

### Annual costs of heat production at Battersea Power Station

The following quantities are measured accurately at Battersea:—

(1) The steam supplied to the back-pressure sets from Battersea "A" steam range.

(2) The heat supplied to the Council.

(3) The electricity supplied (to the Battersea station auxiliary services) from the back-pressure sets.

The performance of the Battersea "A" boilers is known accurately and it is therefore possible to calculate from (1) above the coal consumed to supply the back-pressure sets with their input of heat for conversion into electricity and low-grade heat. The capital cost of the special heat-supply plant is known and the operating and maintenance costs incurred directly on that plant are recorded. The Battersea "A" boiler-house facilities are, however, shared between the back-pressure sets and the main condensing sets at the station and, apart from the fuel cost, the allocation of a proportion of the fixed and running costs and charges associated with these facilities to combined heat-electric generation, although calculated carefully, is necessarily more or less arbitrary. The total cost for combined heat-electric generation also contains another arbitrary element—the value to be placed on the electrical output of the back-pressure sets—which must be assessed before the net additional cost of producing the heat for the Council can be determined.

The costs have been assessed first excluding fixed costs and charges associated with the Battersea "A" boiler-house facilities to show the net additional costs directly incurred by provision of the heat supply. Appropriate proportions of the fixed element of the boiler-house works costs and of the overhead charges attributable to the boiler-house plant and buildings have then been added. This gives a cost which it is considered reasonable to allocate to the heat supply with due regard to the sharing of Battersea "A" boiler-house facilities as mentioned. With the heat supply costed on the first, or "direct" cost basis, the costs of electricity supply are unaffected by the provision of the heat supply. On the second or "allocated" cost basis, electricity supply benefits to the extent of being relieved of a small proportion of the fixed costs associated with the boiler-house facilities.

Capital charges have been calculated on the basis of a 3½% annuity for 25 years for plant and 40 years for boiler-house buildings. Other overhead charges have been calculated at the same percentage of capital cost as the total of such charges in the C.E.A's generation account bears to their total generation capital expenditure. The Battersea "A" boiler-house fixed costs and charges allocated to the heat supply on the allocated costs basis have been assessed with regard to the relation between the steaming capacity required to supply the back-pressure sets and the total installed boiler plant capacity at the station. Since, however, the Battersea boiler-house facilities are shared only half the costs and charges allotted to the heat supply in proportion to steaming capacity have been taken into account. In the years ended 30 September, 1953, and 30 September, 1954, the heat supply could have been provided by one back-pressure set and the full boiler-house costs and charges in these years have therefore been based on the steaming capacity required to steam one set only at continuous maximum rating (C.M.R.). In the estimate of the ultimate annual costs the full costs and charges have been based on the steaming capacity required to steam both sets at C.M.R.

The costs of production at Battersea, assessed on the foregoing basis, for the years

ended 30 September, 1953, and 30 September, 1954, are given in Appendix I with an estimate of the ultimate annual costs when the Undertaking is fully developed. To make the three sets of costs comparable the fuel costs and the values of electrical outputs of the back-pressure sets have been stated at an arbitrary round figure fuel price of 100*s*/ton (including handling, flue-gas washing, and ash-disposal costs) at a calorific value of 12,500 B.t.u./lb. Total costs at the actual fuel prices in the years ended 30 September, 1953, and 30 September, 1954, are, however, also shown.

Although the annual load factor on the back-pressure sets will ultimately be substantially higher than in the years ended 30 September, 1953, and 30 September, 1954, no improvement in their kWh s.o. heat consumption has been assumed because, by the use of the heat accumulator, they operate at a very high plant load factor (ratio of actual to maximum possible output during running hours) irrespective of heat load.

### Hypothetical assessment of ultimate annual costs of heat production at Battersea assuming installation of additional boiler plant

As already mentioned there are special considerations in regard to boiler plant supplying heat to the Council. It was therefore thought interesting to adjust the circumstances to nearer the general case and, despite the small capacity of the back-pressure sets, to apply the method of costing applicable for large-scale back-pressure generation. It was assumed that new main station boilers had been installed at Battersea "A" at the same time as the heat supply plant, with sufficient capacity to meet the maximum steam requirements of condensing and combined heat-electric generation simultaneously. This still represents, to some extent, a special case because the heat supply is assumed to be derived from small back-pressure sets with a low internal efficiency supplied with steam from large highly efficient main station boilers. It is, however, the closest possible generalization for conditions at Battersea.

This assessment was based on the estimated ultimate heat requirements, and the capacity of boiler plant allocated to combined heat-electric generation has been taken as that required to steam the two back-pressure sets at C.M.R. In assessing the boiler-house overhead costs chargeable to combined heat-electric generation the lb/hour cost of output capacity of the hypothetical boiler plant and buildings has been taken at the appropriate figure for plant commissioned in 1951 and is 200% greater than the actual pre-war Battersea "A" boiler house.

After allowing for auxiliaries, the maximum output capacity of the two back-pressure sets is about 2,400 kW but the electrical output obtainable from such sets is governed by the heat requirements. In considering what capacity of condensing plant would be equivalent to the back-pressure plant it is necessary, therefore, to compare the service expected from the latter with that normally required from the former. This comparison has been confined to the day-load hours on the electricity system since lack of electrical output from back-pressure plant at night is unimportant. When the Pimlico Undertaking is fully developed the heat load in the winter months will require the running of both the back-pressure sets at C.M.R. for considerably longer than the day-load hours on the electricity supply system and 2,400 kW sent out will therefore be available throughout those hours. During the generating-plant overhaul period in the summer months about two-thirds of the condensing plant in the C.E.A's system is required to be available to meet the load. With regard to the summer electrical output of back-pressure sets, it is thought that when the Undertaking is fully developed the summer heat load will be sufficient,

with the use of the heat accumulator, to enable about two-thirds of the winter maximum electrical output of the back-pressure plant to be maintained during day-load hours. It was therefore concluded that the service, from the point of view of electrical output, which could be expected from the back-pressure plant during day-load hours on the electricity supply system throughout the year would be similar to that normally required from condensing plant. The condensing generation costs to be deducted from the overall costs of combined heat-electric generation have been taken as the estimated fixed costs of production for plant commissioned in 1951 and having a maximum output capacity of 2,400 kW s.o., together with the estimated running costs of production (calculated in the same way as the costs quoted in Appendix I) to produce the kilowatt-hours supplied from the back-pressure sets.

These hypothetical costs are given in Appendix II. Compared with the estimate of the ultimate annual costs in Appendix I, the additional credit in respect of the kilowatt value of the electrical output of the back-pressure sets has been offset to a considerable extent by the additional boiler-house charges taken into account. The net cost attributed to the heat supply in the hypothetical assessment in Appendix II is, however, a little lower than that on the direct-cost basis in Appendix I.

## Costs of heat transmission and distribution

The Council is required to keep separate accounts for the Undertaking showing capital and revenue expenditure and income. To meet this requirement it is necessary to define the Undertaking, which is regarded as comprising all works between the "point of supply" on the boundary of the Authority's premises at Battersea and the main control valves on the distribution mains where they enter each block of flats. The installations necessary within the flats (pipework, radiators, calorifiers, etc.) are regarded as part of the "housing" or "landlord's" equipment. This division follows that found at Dolphin Square, where the Undertaking supplies heat in bulk to the Dolphin Square Company's installations which remain as they were when connected to the Company's own independent central-heating boiler plant.

The year ended 30 September, 1953, provided useful information on costs of distribution because, as already mentioned, heat was supplied to a constant number of premises throughout that year and relatively little development work was in progress. The premises supplied with heat in that year were:—

| | Number of flats | Approximate number of occupants |
|---|---|---|
| Churchill Gardens (Section I) and Russell House . . . . . . | 569 | 2,190 |
| Dolphin Square . . . . . . | 1,200 | 2,750 |

In addition, relatively small quantities of heat were supplied to thirteen shops, a small hall, and a workshop on the housing estate and to shops, offices, etc., at Dolphin Square.

The year ended 30 September, 1954, does not provide such useful information because during that year work was proceeding on the extension of supply to Section II of Churchill Gardens and to the Abbots Manor Estate. Altogether 194 additional dwellings were connected to the Undertaking in 1954, some of them only for a very short period. Calculated simply on dates of occupation these additional dwellings are equivalent for the full year to approximately sixty-five dwellings, containing about 208 occupants. But this approximation may be misleading since most of

..e dwellings became occupied during the summer months. It is also to be noted ..at during the year an unascertainable amount of heat was used for testing new ..ains and balancing supplies to new premises and that a relatively small amount of ..eat was lost when the heat accumulator was drained for inspection.

### Capital cost of heat transmission, distribution, and storage works

Although the accounts of some contractors have not yet been agreed, the cost of ..e plant and equipment installed for the supply to Section I of Churchill Gardens, ..ussell House, and Dolphin Square (i.e., the premises served throughout 1952–53) ..n be estimated with reasonable accuracy. The total capital cost when the Under..king is fully developed can be estimated only on the basis of present experience and ..osts. The two sets of figures of estimated capital cost are as follows:—

| | Plant installed to supply Churchill Gardens (Section I), Russell Hse, and Dolphin Square (as used in 1952–53 costs) | Plant expected to be installed when Undertaking is fully developed |
|---|---|---|
| | £ | £ |
| Tunnels | 23,600 | 23,600 |
| Reinforced concrete conduits | 19,050 | 215,000 |
| Pipes, machinery, and electrical equipment | 79,950 | |
| Heat accumulator | 40,500 | 40,500 |
| Pump-house and workshop building | 16,150 | 16,150 |
| Site of pump-house and accumulator | 2,900 | 2,900 |
| Miscellaneous | 2,850 | 2,850 |
| Interest on capital during construction | 3,800 | 5,600 |
| | 188,800 | 306,600 |

During the year ended 30 September, 1954, development proceeded rapidly and for ..he purpose of the year's expenditure a charge has been calculated on the approxi..nate capital expenditure to 31 March, 1954, i.e., the mean date.

### Annual costs of heat transmission and distribution

The greater part of the operational cost is directly ascertainable. Some apportion..nent of administrative salaries is necessary; this is done on a time basis. Collection ..f payments by the Council's tenants is carried out by the housing rent collectors ..nd the Undertaking is charged with a sum equal to $2\frac{1}{2}\%$ of the amount collected.

Actual capital charges are related to the time and terms on which the Council ..orrowed. In respect of the capital expenditure on the first part of the development ..£185,000) borrowings were made at an average rate of interest slightly less than ..$\frac{1}{2}\%$ per annum. Subsequent and future borrowings may be expected to increase ..his average. With a view to simplicity and to be uniform with the Authority, the ..harges for the purpose of this Paper have been calculated on the basis of a $3\frac{1}{2}\%$

annuity for the following periods, which are the full periods permitted to the Council: tunnels 40 years, other works and equipment 30 years, and land (site of pump-house and accumulator) 60 years.

Appendix III shows the annual costs for the 2 years ended 30 September 1953 and 1954, together with an estimate of the annual costs when the Undertaking is fully developed.

### Overall annual cost of providing the district-heating supply

The Authority's costs of heat production at Battersea and the Council's costs of heat transmission and distribution are brought together in Appendix IV. The estimated costs per therm delivered to consumers are as follows:—

| Battersea costing basis | Fuel price per ton assumed: | Year ended 30 Sept., 1953: | Year ended 30 Sept., 1954: | Estimated ultimate annual: |
|---|---|---|---|---|
| | *s* | *d*/therm | *d*/therm | *d*/therm |
| Direct . . | 100 | 9·89 | 10·82 | 9·35 |
| Allocated . | 100 | 10·11 | 11·05 | 9·61 |
| Direct . . | Actual | 9·18 | 10·57 | — |
| Allocated . | Actual | 9·40 | 10·79 | — |

### Consideration of the overall cost of the district-heating supply

The cost of providing the Pimlico district-heating supply is influenced by various special circumstances, some favourable, some unfavourable; they are:—

*Favourable*

(1) Large-scale building developments are being carried out in a compact area near a power station.

(2) There was a ready-made route for hot-water transmission mains under the River Thames.

(3) There was a large existing heat load at Dolphin Square which could be connected up as soon as the system was established.

(4) The supply is derived from highly efficient main station boiler plant installed before the war at about one-third the cost of installing the same capacity boiler plant at the time when the heat supply started.

*Unfavourable*

(1) The size of the system is such that the back-pressure sets have a capacity of only 1,350 kW each and such small sets have a low internal efficiency.

(2) The system does not benefit from any large commercial or industrial users of heat.

(3) The electrical output of the back-pressure sets cannot be credited with any capacity value but only with the value of the kilowatt-hours supplied.

The circumstances of each district-heating scheme differ and each scheme must be considered in the light of its own special circumstances. The Pimlico Undertaking cannot therefore be regarded as typical of district-heating schemes and allows only the broad conclusions regarding costs which are given later. However, in the circumstances at Pimlico domestic district-heating supplies can be provided at a reasonable price.

### Distribution-system operation

It may be felt that the cost of operating wages and uniforms, shown in Appendix II, amounting to about £2,500 to £3,000 per year is high for an undertaking of the ze of that at Pimlico. However, the Council is under an obligation to supply heat roughout the 24-hours and the sub-station is therefore continuously manned 7 days week.

Besides being responsible for day-to-day maintenance of plant, the sub-station erator has to keep a close watch on the plant-operating conditions and for the esent is required to make entries in the log each hour of more than thirty items cessary for record and statistical purposes. They include details of water temperares, pressures and quantities, air temperatures, heat intakes and output quantities, nd electrical currents.

The operator has also to watch instruments showing if immediate adjustments are eeded in the operating conditions of the plant. It may be necessary, for example, vary the output of heat to accord with changes in the weather, to discontinue e charging of the accumulator, or to increase its water level.

The part of the system serving the housing estates is started at 6 a.m. and shut own at between 10.30 and 11.30 p.m. according to the severity of the weather. The ipply to Dolphin Square is continuous except during the summer when it is shut own from 1 a.m. to 4 a.m. The operator has therefore to start and stop the respecve circulating pumps at these times including those in Abbots Manor Estate which re operated by remote control.

Another of his important duties is to watch the recorders of the temperatures in a umber of selected living rooms in the flats which vary mainly as a result of changes nown on the external temperature recorder. These two temperatures have to be orrelated closely by the operator, which he does by making the necessary adjustment the flow temperature by controlling the mixing-valve thermostat.

The operator must also watch the accumulator heat-content indicator to ensure nat sufficient heat is available in storage to meet daily fluctuations in heat output emands. He therefore has to keep the power station informed of the quantity of eat to be supplied according to the indicator and has direct communication by elephone with the station. The charging and discharging of the accumulator is ntirely automatic and the operator therefore need operate no changeover valves hen these functions occur simultaneously with, or independently of, the supply of eat from the power station direct to the consumers.

Other duties consist of making periodic checks of the pH value of the water and if ecessary using the water-treatment plant for the mixing of chemicals and feeding onditioned water into the system.

The sump pumps in the sub-station and under-river tunnel are controlled autoatically as is the accumulator emergency isolating valve, but all this equipment nd various audible and visual signals which operate in conjunction with it have to e checked at frequent intervals.

With larger district-heating undertakings and more experience of operation istribution-operating costs per therm may be expected to be reduced considerably.

### General conclusions

The financial results of the Undertaking confirm that the estimates in the original aper for the economy of combined heat-electric generation under such conditions

as at the back-pressure sets at Battersea "A" are close to results obtained in practice. The conditions referred to are the pressure and temperature of initial steam, the back pressure at the turbine exhaust, and the turbine-efficiency ratio.

The estimated costs in the original Paper for a large hypothetical scheme having similar conditions to Battersea "A" (resulting in a ratio $R$ of electrical energy to heat energy sent out of 0·17) represent those to be expected with a heat supply provided from highly efficient boiler plant but from back-pressure sets with a low internal efficiency. These features also apply to the hypothetical estimate given in Appendix II which, apart from the overhead charges on boiler plant, is based on the actual results at Battersea "A." If suitable adjustments are made to put the estimated fuel cost and calorific value and the rate of annual capital charges in the two estimates on a common basis, the prediction made in the original Paper is very similar to the figure brought out in Appendix II of this Paper. This is not surprising because the fuel cost is the preponderating component of the net cost of heat sent out from Battersea "A." The second largest item, namely, annual capital charges, is capable of close estimation based on plant in common use in electrical generation.

It follows that there is the same expectation of accuracy for the prediction of cost per therm sent out for different steam conditions resulting in different values of $R$. In the estimate in Appendix II of this Paper the overall ratio of heat and electrical energy sent out to the heat energy input is about 82% and, although the conditions relate to $R$ at the relatively low level of about 0·17, the net cost of heat sent out from the power station is a little less than the cost price of the heat content of the fuel when used at a combustion efficiency of 82%. It is evident that, with improved thermodynamic cycles giving a higher value of $R$, the net cost of heat sent out would be appreciably reduced.

The attainment of high values of $R$ calls for large-sized units and high steam conditions, and accordingly implies a larger district-heating system than at Pimlico. There is no doubt, however, that the required plant could be constructed and the higher capital costs associated with high steam conditions would be offset to some extent by the intrinsically lower capital cost per kilowatt of large units.

The possibilities of making effective use of the above-mentioned economies depend on the development of a cheap and thermally efficient system of distribution and on the existence of reasonably concentrated heat loads. It is on these considerations that district heating derived from combined heat-electric generation depends for successful development in the future.

## Acknowledgements

The Authors thank the Council of the City of Westminster and the Central Electricity Authority for permission to publish the information given in the Paper.

## APPENDIX I

### Pimlico District Heating Undertaking

#### Annual costs of heat production at Battersea generating station

| | Year ended 30 Sept., 1953 | Year ended 30 Sept., 1954 | Estimated ultimate annual |
|---|---|---|---|
| (1) Heat sent out to City Council: therms . | 1,215,994 | 1,226,032 | 2,000,000 |
| (2) Electricity sent out from back-pressure sets: kWh . . . . . . . . . . | 5,872,800 | 5,962,000 | 9,726,000 |
| (3) Assumed inclusive fuel price per ton at Battersea "A": *s* . . . . . . | 100 | 100 | 100 |
| (4) Assumed calorific value: B.t.u./lb. . . | 12,500 | 12,500 | 12,500 |
| *Costs of production* | £ | £ | £ |
| (5) Fuel . . . . . . . . . . . . . | 30,963 | 31,060 | 50,668 |
| (6) Other works costs excluding fixed element of Battersea "A" boiler-house costs . | 3,936 | 5,373 | 7,000 |
| (7) Overhead charges on heat-supply plant . | 8,403 | 8,782 | 9,314 |
| (8) Direct cost of combined heat-electric generation . . . . . . . . . . | 43,302 | 45,215 | 66,982 |
| (9) Value of electrical output of back-pressure sets . . . . . . . . . . . . | 13,644 | 13,852 | 22,597 |
| (10) Net direct cost of heat production (8) — (9) | 29,658 | 31,363 | 44,385 |
| (11) Proportion of fixed element of Battersea "A" boiler-house works costs allocated to combined heat-electric generation . | 462 | 486 | 970 |
| (12) Proportion of Battersea "A" boiler-house overhead charges allocated to combined heat-electric generation . . . . . | 572 | 572 | 1,144 |
| (13) Total allocated fixed costs (11) + (12) . | 1,034 | 1,058 | 2,114 |
| (14) Net cost of heat production including allocated fixed costs (10) + (13) . . . | 30,692 | 32,421 | 46,499 |
| *Cost per therm sent out* | *d* | *d* | *d* |
| (15) On basis of direct costs (10) ÷ (1) . . | 5·85 | 6·14 | 5·33 |
| (16) After allowing for allocated fixed costs (14) ÷ (1) . . . . . . . . . | 6·06 | 6·35 | 5·58 |
| *Costs at actual Battersea "A" fuel price* | | | |
| (17) Inclusive fuel price per ton. . . . . | 82*s* 6·6*d* | 94*s* 6·0*d* | — |
| (18) Calorific value: B.t.u./lb. . . . . . | 12,755 | 12,707 | — |
| | £ | £ | |
| (19) Net direct cost of heat production . . | 26,279 | 30,136 | — |
| (20) Net cost of heat production including allocated fixed costs . . . . . . . | 27,313 | 31,194 | — |
| *Cost per therm sent out at actual Battersea "A" fuel price* | *d* | *d* | |
| (21) On basis of direct costs (19) ÷ (1) . . | 5·19 | 5·90 | — |
| (22) After allowing for allocated fixed costs (20)÷(1) . . . . . . . . . . | 5·39 | 6·11 | — |

## APPENDIX II

### Pimlico District Heating Undertaking

HYPOTHETICAL ASSESSMENT OF ULTIMATE ANNUAL COSTS OF HEAT PRODUCTION AT BATTERSEA GENERATING STATION ASSUMING ADDITIONAL BOILER PLANT TO HAVE BEEN INSTALLED

| | |
|---|---|
| (1) Heat sent out to City Council: therms | 2,000,000 |
| (2) Electricity sent out from back-pressure sets: kWh | 9,726,000 |
| (3) Assumed inclusive fuel cost per ton: *s* | 100 |
| (4) Assumed calorific value: B.t.u./lb. | 12,500 |
| *Costs of production* | £ |
| (5) Fuel | 50,668 |
| (6) Other works costs | 8,940 |
| (7) Overhead charges on heat supply plant | 9,314 |
| (8) Overhead charges on boiler plant | 6,864 |
| (9) Total cost of combined heat-electric generation | 75,786 |
| (10) Value of kW sent out by back-pressure sets | 11,280 |
| (11) Value of kWh sent out of back-pressure sets | 22,597 |
| (12) Total value of electrical output of back-pressure sets (10) + (11) | 33,877 |
| (13) Net cost of heat production (9) − (12) | 41,909 |
| (14) Cost per therm sent out (13) ÷ (1) | 5·03*d* |

## APPENDIX III

### Pimlico District Heating Undertaking

ANNUAL COST OF TRANSMISSION AND DISTRIBUTION OF HEAT

| | Year ended 30 Sept., 1953 | Year ended 30 Sept., 1954 | Estimated ultimate annual |
|---|---|---|---|
| Heat received from C.E.A: therms | 1,215,994 | 1,226,032 | 2,000,000 |
| | £ | £ | £ |
| Operating wages and uniforms (including pension fund and National Insurance contributions) | 2,572 | 2,991 | 3,000 |
| Rent, rates, and insurances | 1,195 | 1,248 | 3,100 |
| Electricity and water | 604 | 788 | 1,100 |
| Repairs and maintenance | 985 | 1,181 | 2,000 |
| Loan charges | 10,046 | 12,264 | 16,450 |
| Supervisory and administrative salaries (including superannuation fund contributions and National Insurance) and collection of charges | 1,556 | 1,474 | 2,600 |
| Miscellaneous expenses | 147 | 206 | 250 |
| | 17,105 | 20,152 | 28,500 |

*Note:*—Repairs and Maintenance. In each of the years 1952–53 and 1953–54 this includes £100 for purchase of spare parts held available for future maintenance work and in the year 1953–54 it includes £150 for the emptying and inspection of the hot-water accumulator. The Council's insurers have indicated that, as a result of this inspection, they will not require a further inspection for 5 years.

## APPENDIX IV

### Pimlico District Heating Undertaking

OVERALL ANNUAL COST OF PROVIDING THE DISTRICT-HEATING SUPPLY

| | Year ended 30 Sept., 1953 | Year ended 30 Sept., 1954 | Estimated ultimate annual |
|---|---|---|---|
| (1) Estimated heat delivered to consumers: therms | 1,134,675 | 1,142,317 | 1,870,000 |
| (2) Assumed inclusive fuel price per ton at Battersea "A": *s* | 100 | 100 | 100 |
| (3) Assumed calorific value: B.t.u./lb. | 12,500 | 12,500 | 12,500 |
| *Costs of production, transmission, and distribution* | £ | £ | £ |
| (4) Cost of heat production at Battersea on direct-cost basis | 29,658 | 31,363 | 44,385 |
| (5) Cost of heat production at Battersea on allocated cost basis | 30,692 | 32,421 | 46,499 |
| (6) Cost of heat transmission and distribution | 17,105 | 20,152 | 28,500 |
| (7) Overall cost on direct production cost basis (4) + (6) | 46,763 | 51,515 | 72,885 |
| (8) Overall cost on allocated production cost basis (5) + (6) | 47,797 | 52,573 | 74,999 |
| *Cost per therm delivered to consumers* | *d* | *d* | *d* |
| (9) With production cost on direct cost basis | 9·89 | 10·82 | 9·35 |
| (10) With production cost on allocated cost basis | 10·11 | 11·05 | 9·61 |
| *Costs at actual Battersea "A" fuel price* | | | |
| (11) Inclusive fuel price per ton | 82*s* 6·6*d* | 94*s* 6·0*d* | — |
| (12) Calorific value: B.t.u./lb. | 12,755 | 12,707 | — |
| | £ | £ | |
| (13) Overall cost on direct production cost basis | 43,384 | 50,288 | — |
| (14) Overall cost on allocated production cost basis | 44,418 | 51,346 | — |
| *Cost per therm delivered to consumers at Battersea "A" actual fuel price* | | | |
| (15) With production cost on direct cost basis | 9·18 | 10·57 | — |
| (16) With production cost on allocated cost basis | 9·40 | 10·79 | — |

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The Paper, which was received on 18 October, 1955, is accompanied by one diagram from which the Figure in the text has been prepared, and by four Appendices.

## Discussion

**Mr W. B. Noddings** (Chief Commercial Officer, Central Electricity Authority) said that it was well known that very great difficulty and many problems arose in allocating the costs of a combined product; for example, what was the cost of wool and what was the cost of lamb? It was clear that the particular solution must depend on the particular circumstances. The Authors had stated that in Germany more than sixty different methods of cost allocation between electricity and heat supply had been used. The Authors deserved sympathy in having to make the difficult choice between all the methods available, but he thought it would be agreed that in the solution which they had adopted they were certainly not biased in favour of electricity, and it might be said that they had erred, if at all, in the direction of showing a very favourable charge to the heat supply. They had explained that in the hypothetical scheme for the ultimate development they had credited the kilowatt output of the back-pressure plant with a full kilowatt charge, on the ground that in the case in question the accumulator permitted the operation of the station in such a way that the output of the station broadly followed the requirements of the electricity supply system. That was a very fair basis of assessment in the particular case considered, but there might be other cases of district heating where those circumstances would not apply and where the output from a station might in summer be less than the appropriate proportion of the winter output which was required by the seasonal variation in the electricity requirements. In that case, of course, it would be appropriate to devalue the kilowatts.

Many interesting figures were given in the Paper, and others could be derived from those given. It seemed that the overall efficiency of conversion—i.e., the energy supplied by way of electricity and heat related to the heat input in the coal—was of the order of 80%. The corresponding figure if the two supplies, of electricity and heat, were derived independently, the one by electricity production in the normal way and the other by independent central heating, was about 55%. The figure of 27% had been given by the Authors for electricity production, and a figure of 60 to 65% might be taken for independent central heating.

The coal saving for the scheme when in full operation would be between 4,500 and 5,000 tons per annum for a total additional capital expenditure of £430,000 (which excluded the cost of the boiler plant at Battersea), so that it took something like £90 to save 1 ton of coal per annum. In that connexion it would be recalled that the Report on Fuel Conservation of the Anglo-American Productivity Council estimated that by converting hand-fired boilers throughout the United Kingdom to mechanical firing a saving of 3,500,000 tons of coal could be effected for an expenditure of £12,000,000, which meant spending £4 to save 1 ton of coal per annum. In the present days of capital shortage it was clear where money could be used to better advantage if it were a question of coal saving.

The cost of heat delivered to each block of flats had been given by the Authors as roughly 10*d*/therm. Heat on tap at that figure sounded very attractive, but it must be remembered that the standard of heating which the Westminster City Council's tenants enjoyed was a fairly high one. The average figure for the flats given by the Authors was 640 therms per annum per flat, which was 20% higher, he believed, than the figure quoted when the scheme had first been mooted. So far as the Council's flats were concerned he understood that the average weekly charge per flat was of the order of 11 to 12*s*, or about £30 per annum. In addition to that, of course, the tenants had to provide for cooking, lighting, and the other incidentals of the electrical age, and also for gas and electrical appliances. Therefore, although the heat was cheap, the annual cost to the tenants of their combined requirements of heat and energy was bound to be a fairly large item in their annual budget, and more than they would be likely to spend if they had to provide those services for themselves. A social survey inquiry made some years ago had shown that households of the same average size generally spent something of the order of £23 per annum on their raw fuel, gas, and electricity requirements taken together.

That was the difficulty which had been experienced in other schemes for domestic district heating which had been investigated; the fixed weekly charge was beyond what the consumers were prepared to pay. That applied also to the Continent, where domestic district heating was usually confined to blocks of flats occupied by the higher income groups, where the flats would normally otherwise have been supplied with heat by the landlord from a central heating system. In many Continental district heating schemes, moreover, the domestic district heating was only a small adjunct to a general scheme for supplying commercial blocks and public buildings. For example, Hamburg was often cited as a classic example of town heating, and the article quoted by the Authors referred to the Hamburg results for 1954 and showed that domestic district heating accounted for less than 6% of the total town supply. In the United Kingdom people were less flat-minded than on the Continent, and those who could afford the standard of comfort necessary for successful district heating were unlikely to be attracted, in the numbers required for a successful district heating scheme, to blocks of flats in the immediate vicinity of power stations. It was also true that modern power stations were being sited farther and farther away from the centres of living. It seemed, therefore, that the prospects of any major developments of domestic district heating on the lines of the Pimlico scheme, with concentrated domestic district heating near to a power station in the middle of London, were rather limited.

**Mr H. S. Horsman** (Efficiency and Testing Engineer, Central Electricity Authority) said that the Authors had stressed the difficulty they had experienced in trying to present a strictly accurate analysis of the available data at their disposal; some of those difficulties were mentioned in the Paper and the circumstances were such that all who appreciated the nature of the problem would sympathize. The accountancy troubles were apparently not yet over for he believed that the boilers would require renewal in about 8 years' time and that would mean a change in the details of the economics.

In the present system of accountancy the whole of the thermal benefit brought about by the dual generation of heat and electricity was conferred upon the heating supply and Mr Horsman agreed with the Authors that, in equity, some portion of the advantage should go to electricity. The Paper, in fact, contained enough information to show that a gain of 5% in electrical charges would produce an increase in the price of district heating of the modest sum of 0·13*d*/therm.

In view of the accountancy difficulties the Authors were wise to present a hypothetical case in which boilers were assumed to be installed concurrently with the turbo-generators. It was very interesting to note that under such circumstances the price of heat as delivered to consumers would be reduced by about 5%. That hypothetical case provoked further speculation concerning reductions in the price of heat and, to that end, suggestions had been made by the Authors in their general conclusions. In the case of a similar district heating scheme which could conceivably be required in the future it might be advisable to deal with a housing estate containing at least twice the number of dwellings to be found at Pimlico. It would also be advantageous to derive heat from a power station in which spare boiler plant capacity existed; that was a condition found in all new P.F. fired power stations. Presumably there would be two back-pressure sets but they would be much larger than those considered in the Paper. The turbines should be specially designed for their duty and they might conceivably exhaust at several inches of vacuum instead of 17 lb/sq. in. absolute, the extra back-pressure being decided by economic study. Proceeding in that way the Authors' ratio $R$ could be increased with noticeable improvement in the earning power of the capital invested. That arose from the fact that the income from a quantity of heat in the form of electricity was about six times the income from the same quantity of heat transferred to hot water for domestic heating. It was therefore of the utmost importance to obtain the maximum heat drop in the turbine.

It was a great pity that the scheme, predominantly intended for the heating of dwellings as distinct from commercial and industrial premises, should be handicapped in several ways, as mentioned in the Paper. The Pimlico experiment had, however, a value which could not be expressed in terms of money; it demonstrated the feasibility of heat-electric

operation for district heating purposes as such and could serve as an excellent starting point in the consideration of the design of other district heating plants, the necessity for which was becoming more pressing as the price of fuel soared and as the clamour for clean air increased.

Mr Horsman thought the present occasion should not be allowed to pass without reference to the display of enterprise by those who had pioneered in the provision of the Pimlico pilot plant; he included the Westminster City Council, who were to be congratulated upon the fundamental part which they had played in that unique development.

Whatever the ultimate economic verdict might be, the Pimlico figures whether favourable or otherwise were sure to form a sound basis for efficient and profitable planning in the future. The Authors would have the satisfaction of knowing that their Paper had contributed very materially to the dissemination of a large quantity of useful information.

**Mr V. G. Newman** (Hydro, Industrial, and District Heating Engineer, Generation Design Department, Central Electricity Authority) confined his remarks to one feature of the scheme—the heat accumulator. It had been, he believed, introduced into Great Britain by the late Mr A. E. Margolis, following his successful application of it in district heating schemes on the Continent. It seemed, however, that the present trend abroad was away from the use of the heat accumulator. Mr Newman had therefore thought it of some interest to attempt to assess the value of the accumulator in the Pimlico scheme as a guide to future practice in Britain.

The theoretical case for the heat accumulator rested on the following considerations. The capital cost per kilowatt of installed generating capacity was higher for back-pressure generating plant than for condensing plant. In consequence, on the basis of costing adopted by the Authors the fixed charges on the heat-electric plant were higher than the value of the kilowatt output. It followed that the cost of heat at the turbine exhaust would be least when the capacity of the heat-supply plant was the minimum. In other words, the load factor on the heat-supply plant should be as high as possible.

That condition could be achieved with the heat accumulator by sizing the heat-electric plant so that it was just capable of supplying the heat demand on the coldest day when operating continuously for 24 hours on full output. Under those conditions the savings which arose fell under three heads. First, there was a saving on capital cost; secondly, there was a saving on the increased firm kilowatt output which the Authors had mentioned; and thirdly, there was an increase in the value of the kilowatt-hours generated because of the higher turbine efficiency at the improved load factor.

The estimates which he had made related to the ultimate Pimlico development and were as followed. Taking the hypothetical case of additional boiler capacity being installed, the accumulator would show a net saving in capital cost of the whole scheme of £26,000; it would show a net saving in annual costs of heat production of £2,300 on the fixed costs of generation and of £4,100 on the increased firm kilowatt output, plus £3,900 on the increased kilowatt-hours output. Against those there would be an increase of £1,300 per annum in respect of fuel costs for the additional electrical output. On balance, therefore, the accumulator would save £9,000 per annum in addition to the saving of £26,000 on initial cost.

Under the conditions actually obtaining in the Pimlico scheme, where there was a shortage of boiler plant, the fixed costs would be increased by £700 per annum and it would not be possible to credit any firm kilowatt value; but on balance the accumulator, which in the present case entailed an extra capital cost of £27,000, still showed an annual saving of approximately £1,900.

Those figures seemed to show not only that a heat accumulator was fully justified at Pimlico but that in any future scheme, which might be rather more typical, the savings could be really quite considerable. What did the Authors believe to be the reason for the apparent passing into disfavour of the heat accumulator on the Continent?

**Mr D. J. Bolton** (formerly of the Central Electricity Authority) said that there were two ways of running a back-pressure set; either during the hours which best suited the

electricity supply or during such hours as suited the heat supply. In the former case the electricity was worth more, because some firm kilowatts were obtained, but there was the disadvantage that it was necessary to pay for considerable equipment in the form of heat storage and control gear. In the calculations in Appendices I and IV the Authors appeared to have succeeded in making the worst of both worlds. Heat storage and control equipment were provided on a very elaborate scale, and at the same time the electricity generated was credited only with its kilowatt-hour value. It was encouraging to find that, in spite of that handicap, the results showed that the heat could be supplied at an acceptable figure. The alarming fact, on the other hand, was that about 37% of the overall cost was spent in taking the heat the ½ mile from Battersea to the housing estate. One shuddered to think what the cost would be of doing the job in a less concentrated load area.

Looking ahead, the future would seem to lie with storage schemes having firm kilowatt value rather than with schemes with what might be described as "run-of-river" characteristics. The latter could do no more than save fuel, and, as Mr Noddings had pointed out, there were less expensive ways of doing that. In proportion to the capital involved, dual heat and electricity supply was rarely an economic way of saving coal, but it might well prove economical when there was a kilowatt saving as well. In the future—the atomic energy future—it might be that the most important function for the remaining coal-fired stations would be to produce kilowatts at the right moment of the day and year.

The future heat and power systems must then have their accumulators, and one could anticipate seeing London and other large towns punctuated with those magnificent aluminium and glass towers!

**Mr C. G. Carrothers** (Engineer-in-Charge, Research Department, Kennedy and Donkin, Consulting Engineers, London) referred to Mr Newman's comment on the present trend on the Continent to depart from the use of the heat accumulator. The heat accumulator had been first developed in Hamburg and had been looked upon by the designers as an important part of the scheme; and, for the reasons which Mr Newman had outlined for Pimlico, it had had an important effect on the economy. At the present time, however, there was a tendency in Continental schemes to use pass-out turbines rather than back-pressure turbines. In consequence, there was not the same saving in capital by the use of an accumulator, because usually the pass-out sets were very large, operating partly condensing, and the alteration in their size by omitting the accumulator would be insignificant. That fact accounted almost wholly, he believed, for the loss of favour of the accumulator on the Continent.

**Mr C. L. Champion** (Superintending Engineer, Ministry of Works) congratulated the Authors on giving publicity to figures obtained from the operation of a district heating scheme over a period of years. Since the war quite a number of district heating schemes of one sort or another had been installed, but in most cases there had been a deplorable lack of information with regard to the results actually obtained. It was particularly encouraging to find that in the Pimlico scheme the actual costs of heat generation fitted in quite closely with those originally estimated.

It had been said that the Pimlico type of installation was unique in Britain. It seemed to him that that was a deplorable fact, and he knew of no other comparable installation which was following it up. In the large amount of building work which had been started within the past year or two other methods of heating were being employed. In particular, a number of considerable housing developments by local authorities had been provided with only electric heating. It had been argued that the use of electric heating could be justified economically, but he thought that the figures given in the Paper must show that that was not so, because to provide the same amount of heat for the flats served by the Pimlico scheme by electricity would cost approximately three times as much.

It had been said that the cost to a flat dweller in the Pimlico scheme was of the order of £30 per annum, which meant that it would cost £90 to heat such a flat equally well electrically. It was obvious that the tenants either could not afford or would not be prepared to pay such a sum. What actually happened in the case of electrically heated

schemes was that the standard of heating provided was very much lower than at Pimlico. Some people in Britain apparently regarded it almost as a matter of pride to live in uncomfortable conditions and the provision of heating on the Pimlico scale represented a very real improvement in the standard of living to which most people had been accustomed. Nevertheless, any increase in the standard of living had to be paid for, and it seemed to him very important in such schemes that the charges should represent the full cost of heat supply and should not contain any element of subsidy.

**Mr C. M. Johnston,** in reply, agreed in general with the comments of Mr Noddings, who had pointed out that the comparison of the efficiency of combined heat-electric generation with that of condensing generation plus independent central heating was not a comparison of an efficiency of the order of 80% with one of 20–30% but of 80% with something more than 50%. With regard to the capital which it was worth spending to save 1 ton of coal per annum, if account were taken of the marginal cost of coal production in the United Kingdom or of the import price it might be possible to argue that, if the capital were available, it would be worth while in the national interest to spend £100 or more to save 1 ton of coal per annum.

Mr Horsman wanted electricity to benefit a little more from combined generation. Mr Johnston was sorry if the Authors had not been kind enough to electricity but the sharing of the benefit between electricity and heat supply was a matter of policy which, as mentioned in the Paper, was not pursued therein. Whilst hesitating to say anything about a set designed for the job, Mr Johnston thought that that was obviously a desirable requirement.

Mr Carrothers had replied to Mr Newman's question of why the heat accumulator seemed to be going out of fashion on the Continent. Mr Carrothers had mentioned that on the Continent pass-out sets were preferred to back-pressure sets, and it might be added that the type of set installed would give maximum heat output and limited electrical output or maximum electrical output and limited heat output. It might be thought that with a set of that type there would be a shortage of electrical output in the winter months, but conditions on the Continent differed from those in Britain in that the heat peak and the electrical peak did not as a rule coincide, and the district heating undertakings seemed to rely to a considerable extent on the heat-storage capacity of the district heating system itself, rather than on that of an accumulator. Mr Johnston had heard it said that in Berlin they were of opinion that they could shut the whole district heating supply off for 2 hours and no one would notice.

Mr Bolton regretted the fact that there was a good deal of expenditure at Pimlico on heat storage with no kilowatt value, but Mr Newman had shown that despite that the accumulator was justified.

Mr Champion deplored the fact that no other similar schemes were on the way, but, as Mr Noddings had pointed out, whilst the heat might be cheap the annual cost, in view of the standard of heating provided, was high, and in Britain there were not enough people who were prepared to pay to be comfortable.

**Mr Edward Ockenden,** in reply, said that Mr Noddings had quite rightly drawn attention to the cost of the heating to the tenants of the Council's flats, which, as he had said, was of the order of £30 per annum. That had been very much in the minds of the City Council when they had first considered, with the old London Power Company, the introduction of the Pimlico scheme; they wondered whether or not their tenants would be able to afford it. In the event there had not been any real difficulty, possibly because the period had been one of inflation and wages had risen steadily. The fact remained, however, that the tenants did not seem to find any real difficulty in meeting the cost.

Mr Ockenden had spoken to the Council's housing manager on the subject only a week ago and had asked her whether she felt that the tenants found the charge too much of a burden and also whether or not, given the opportunity, they would prefer a flat having one of the traditional forms of heating, so that they could themselves regulate the amount

which they would spend on heating. She had replied that there were one or two people living in the old pre-war estates of the Council who did not want to go to the new estates because they were fearful of the charge for heat, but that on the other hand she had not found one tenant in the new estates who would be prepared to go back to the old. Apparently people had become accustomed to the amenities and seemed prepared to pay for them.

Mr Champion had expressed the view that there should be no subsidy and that the charge made for the heat should be its cost. The Council were required, by the statute under which the scheme had been carried out, to make its income equal its expenditure over a period in so far as it was reasonably possible to do so, and it was the policy of the Council to do just that. No doubt they would have to face increases in the charges, because they were dependent on the price of coal; but the Council were honestly facing the fact that they must over the years—not when there was only a small load on the scheme—recoup those costs.

Mr Ockenden had gathered from the discussion that there was no doubt in anyone's mind that heat-electric generation held possibilities of very great savings in the consumption of fuel. The real problem, as was stated in the Paper, was one of distribution. That was a factor which the Council had examined very carefully throughout. They regarded the scheme as a prototype and felt that the one thing of which they must be certain was that it would work and continue working under all conditions. It might be that others, coming after them, could learn from their experience and do things more economically. One of the Council's great concerns had been the cost of providing the ducts through which the heating pipes were laid from the pump-house to the various blocks of flats.

In the Table on p. 331, dealing with capital costs, there were two figures which he thought were of great interest relating to capital costs for the plant installed for the first section of the scheme: tunnels, £23,600, and reinforced concrete conduits, £19,050. It should perhaps be explained that the tunnels did not refer to the tunnel under the Thames but to two other tunnels—one from the power station to the Water Board's tunnel on the south bank of the river and the other on the north bank from the point where the mains left the Water Board's tunnel to the pump-house; whilst the concrete ducts were for the pipes to the various blocks of flats. That was a very considerable expenditure on a pure distribution system, and amounted to about 23% of the Council's capital expenditure. It seemed possible that by the exercise of ingenuity some real saving might be possible there.

**Mr Donkin**, in reply, referred to Mr Noddings's way of relating the capital expenditure on Pimlico to the saving of coal, and pointed out that the investment of £430,000 which he had mentioned was not only to save coal but also to give a supply of electricity and heat which could not be given without comparable capital expenditure by any other method.

Mr Horsman had referred to the replacement of the boilers concerned in the Pimlico Scheme in about 8 years. That might be made the occasion for the replacement of the back-pressure turbo-generating plant by sets operating between wider limits of initial steam and vacuum conditions, thus increasing the ratio of electricity to heat from its present value of 0·166 to 0·5 and so trebling the revenue produced from electricity and reducing the net cost of production of heat to less than one-half of the amount shown by Appendix I, item 10. Mr Horsman had also called attention to the value of the Scheme as a prototype, in which capacity it suffered some handicaps, and to its contribution to the cause of clean air. The Authors thanked Mr Horsman for mentioning those points, also for his reference to the part played by the Westminster City Council in launching the Pimlico Scheme.

Mr Bolton had put his finger on the main handicap of district heating, namely, the cost of distribution. It might, however, be hoped that the interposition of a river between the source of heat and the premises to be heated was not to be taken as standard practice.

As pointed out at the end of the Paper, research on the development of a cheap and thermally efficient system of distribution was a matter of primary importance if combined heat-electric generation was to be effective.

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The closing date for Correspondence on the foregoing Paper was 15 May, 1956. No contribution received later than that date will be published in the Proceedings. —SEC.

# ORDINARY MEETING

14 February, 1956

WILLIAM KELLY WALLACE, C.B.E., President, in the Chair

The Council reported that they had recently transferred to the class of

*Members*

Bonnyman, George Alexander.
Casserly, Michael John Paul, B.E. (*National*), B.Eng. (*Galway*).
Cooper, George Henry Colin.
Dyer, Edward Arthur, B.Sc.(Eng.) (*Lond.*).
Hooker, Arthur Vernon Robert.
Hope, Adam, B.Sc.Tech. (*Manchester*).
Isaac, Peter Charles Gerald, S.M. (*Havard*), B.Sc.(Eng.) (*Lond.*).
Kavan, Prabh Dyal, B.Sc. (*Glas.*).
Kesson, James McFarlane, B.Sc. (*Glas.*).
Lewis-Bowen, Gerard Arthur, B.A. (*Cantab.*).
Marc, Ralph Chevalier, M.Sc.(Eng.) (*Lond.*).
Moon, Derrick Ivor Barrington, B.Sc. (*Manchester*).
Spence, William Stuart, B.Sc. (*Aberdeen*).
Vandy, Thomas Steel.
Widdowson, Jack.

and had admitted as

*Graduates*

Abbey, Charles Henry, B.A. (*Cantab.*).
Andrews, Allan Peter, B.Sc.(Eng.) (*London*).
Armstrong, Frank, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
Bailey, Bruce Owen, B.Sc. (*Birmingham*).
Bassett, Jonathan William, B.A. (*Cantab.*), Stud.I.C.E.
Bickerton, David James, B.Sc. (*Bristol*).
Biviji, Shiraz Abdeali, B.E. (*Poona*).
Blankevoort, Nicolaas.
Booth, John Patrick Maurice, Stud.I.C.E.
Bowie, Ian George, B.Sc. (*Manchester*), Stud.I.C.E.
Butcher, Edgar Ernest, Stud.I.C.E.
Calder, John Lyall, B.Eng. (*Liverpool*).
Caley, Neale Jarvis, B.Sc. (*Manchester*).
Carr, James Robert Moncrieff, B.Sc. (*Bristol*), Stud.I.C.E.
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and had admitted as

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…EEN, Philip Arthur.
…EEN, Timothy John.
…IFFIN, Nicolas Luckman.
…OVES, Donald Frederick.
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…ALLAM, Anthony Rodely.
…ARRIS, Vincent Anthony Paschal.
…AVERS, Geoffrey Ernest.
…LL, David Arthur.
…RST, John Edward.
…OBBIN, Richard Ramsay.
…SSELL, David John Trevis.
…MES, Peter Wilson.
…NNELL, David.
…RWAN, Edward Patrick Delaval.
…NGRAN, Michael Antony.
…ADBETTER, Kenneth Edward.
…MON, Terence Ernest Horace.
…WENDON, Roger Stewart.
…DLEY, John Harwood.
…cArthur, Ralph Malcolm.
…Combe, Francis Michael.
…Cormack, John.
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…Millan, Paul Ronald.
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…EDLYCOTT, Robert Adrian.
…ELDRUM, Peter Hugh.
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Morison, Neil James.
Mountain, Keith.
Mulroy, Terence Michael.
Nimmo, Brian Sidney.
Ogle, Martin.
Oliver, John.
Osborne, Frederick David.
Owen, Edwin Kingsley.
Pain, David John.
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Parkhouse, John George.
Percy, Peter George Brian.
Powell, Frank.
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Redwood, Richard George.
Rizq, Elias Hanna.
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Shiels, John Thomson.
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The following Paper was presented for discussion and, on the motion of the …resident, the thanks of the Institution were accorded to the Authors.

Paper No. 6094

# THE DESIGN AND CONSTRUCTION OF ADEN OIL HARBOUR

by

* John Elliott George Palmer, M.A., M.I.C.E., and
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## SYNOPSIS

In 1951 the Anglo-Iranian Oil Company, pursuing their policy of constructing refineries at points where the products were required, were considering building a refinery within the colony of Aden, Aden being primarily a bunkering port, handling about 3,000,000 tons of oil per annum. A reconnaissance party was sent out in September 1951 and a site for the refinery was selected, which controlled the choice of site for the new harbour required with tanker berths to serve the refinery.

Since a berth had to be ready to unload oil for the refinery, speed was essential and figured largely in the design. The layout of the harbour and the factors influencing the design adopted are described.

After initial trials of various methods of quarrying, the contractor elected to concentrate on heading blasts; figures are given of the percentage of large stone suitable for armour thus obtained.

The breakwater core was constructed entirely by tipping rock from Euclid wagons. This method influenced the design and specification and details are given.

Rubble mounds to contain the reclamation were also tipped from Euclids and made tight by a seal of crushed stone to contain the fine sand dredged and pumped ashore.

A special rolling of hexagonal steel piles was adopted for the jetties. Three piles were driven and test loaded; details of the tests are given.

The framework of the jetty was of steel sections welded together; inspection of the welding included gamma-ray photographs. The jetty decks were of precast concrete slabs used as soffit shuttering and incorporated as part of the deck.

Built-up steel fender piles were driven to a batter in front of the berthing faces and the berthing forces transmitted from them to the main framework through compression rubber blocks.

The dredging of the harbour area and approach channel amounted to about 6,000,000 cu. yd; a separate contract and a list of the plant used is given.

For concrete making, only dune sand, a very fine sand with a high percentage of shell, was at first available and the steps taken to produce good sand are described.

Living conditions on the site were excellent; all European accommodation was air-conditioned and the food was good, which materially assisted speed of construction and reduced sickness.

The first tanker was berthed on the 17th July, 1954, and the harbour contract was considered complete on the 10th September, 1954, 22 months after work commenced on the site and more than 3 months ahead of contract time. The dredging of the main harbour area was completed 7 weeks ahead of contract time.

## Introduction

Aden for many years has been one of the world's largest bunkering ports since it lies on the sea route between Europe and East Africa, the Middle East, the Far East, and Australia. Once a coaling port, it has now turned over almost entirely to oil.

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ıtil recently Aden harbour (Fig. 1) possessed no berths where sea-going ships could me alongside and all vessels were moored at buoys where they were bunkered ·ough submarine pipelines; the total quantity bunkered was approximately ·00,000 tons annually. In 1951 the Anglo-Iranian Oil Company (as it was then med), pursuing their policy of building refineries close to places where there is a ostantial demand for the refinery products, were considering the construction of a inery at or near Aden harbour. The Company arranged for a reconnaissance party visit the site, and asked their consulting engineers to send a representative; a rtner, one of the Authors of this Paper, was selected for this visit. The other .thor is the Resident Engineer appointed by the consulting engineers for the super- ion of the construction of the oil harbour.


FIG. 1.—SITE PLAN

The Paper is concerned mainly with the design and construction of the oil harbour .t the first problem was the siting of the harbour which was, of course, largely pendent on the site selected for the refinery. On the reconnaissance visit in ptember and October 1951, three sites for the refinery and four sites for the oil .rbour were investigated. The party also investigated problems of road access, ıter supply, labour available, local building materials, and the like.

As a result of this reconnaissance the site for the refinery was fixed on Little Aden ninsula which forms the western boundary to Tawayih Bay, the large and well- fined bay which has the main Aden peninsula as its eastern arm, where Aden com- ercial harbour is sited. Fig. 2 (facing p. 354) is an aerial view showing the nfiguration of this part of the coast, the direct distance from Steamer Point on Aden ninsula to the opposite point on Little Aden peninsula being 4 miles. Little Aden ninsula consists mainly of volcanic hills but has one fairly flat area towards the

eastern end and this was the area chosen for the refinery. It is bounded by the sea at Khor Ghadir on the south, by the Khor Bir Ahmad on the north, and by two steep hills, Jebel Am Muzalkam on the west, and Jebel Ihsan on the east. The refinery itself is sited on ground sloping gently, at about 1 in 50, to the east from Muzalkam.

A preliminary report dated October 1951 was prepared by the consulting engineers, in which possible sites for the oil harbour were reviewed and in which a site at the north-east extremity of the Little Aden peninsula was favoured. In a further report dated January 1952 the site proposed for the oil harbour was moved a few hundred feet southwards towards deep water in an attempt to reduce dredging. All the layouts prepared up to that date were necessarily only preliminary layouts, since no borings were available to prove whether the areas proposed for the dredging were free from rock. An early start on the borings to prove the feasibility of dredging the site was recommended in the January 1952 report.

A hydrographic survey of the area and a large number of borings had meanwhile been undertaken on behalf of the Aden Port Trust, in conjunction with the oil company, and preliminary results were received in March 1952. Among other considerations hard material was encountered in one or two of the borings, rendering it essential to move back the oil harbour again towards the north and also slightly farther away from the Little Aden peninsula.

Additional borings were carried out between July and November 1952, the results of which finally confirmed that the dredged area proposed for the oil harbour was free from rock; no further modification of the scheme on that account was necessary.

The oil company had meanwhile selected the main contractors for the construction of the oil harbour, and the Authors of the Paper, with representatives of the contractors, visited Little Aden in July 1952. Their main object was to examine the suitability of the various rocks at Little Aden and to determine the most promising quarry sites for the large blocks needed in the breakwater.

It was decided that the refinery could be constructed in 25 months and that the oil harbour would also, therefore, have to be built in the same short period of time. Since contract drawings had, at that date, only just been put in hand there was clearly no time to prepare the usual detailed schedule of quantities for the contractor to price before commencing work. A "target cost" form of contract was therefore adopted for the whole of the oil harbour, apart from the dredging.

The dredging could be defined fairly closely and it was therefore made the subject of a firm-priced schedule contract. Separate items were included in the bill of quantities for the cost of transport of the dredging plant to Aden and for its removal from site in order to cover possible variations in the quantity to be dredged without unfairness to either oil company or contractor.

## The siting of the oil harbour

The siting and layout of an entirely new harbour is one of the most fascinating problems with which civil engineers have to deal. In the case of the new oil harbour for the Aden refinery, it is clear from a study of the configuration of the coastline that there are two good alternative sites for a new harbour in Tawayih Bay. One site examined during the 1951 reconnaissance is at the eastern end of the bay just north of the existing Aden harbour. It would be well sheltered by Aden peninsula from the east, the south-east, and the south but would require artificial protection against storms from the south-west. The alternative site, on the western side of the bay, is sheltered from the south-west by Little Aden peninsula but requires a

eakwater against possible storms from the south and rough weather from the uth-east. The consulting engineers favoured the western site for the oil harbour, ace they believe that the heaviest storms in the Gulf of Aden occur during the uth-west monsoon, and the western site is well sheltered from the south-west. hen the oil company experts on the reconnaissance decided that Little Aden was e best site for the refinery, the general siting of the oil harbour appeared to be ttled.

Three sites for the construction of the refinery were examined by the reconnaissance rty. These were:—

(1) East of Hiswa village, on the northern edge of the bay.
(2) West of Hiswa village, on the north-western edge of the bay.
(3) The Little Aden peninsula.

Considerations influencing the selection of site (3) were the evenness of the terrain, e trouble to be expected from blowing sand at the other two sites, the excellent aring capacity of the ground, the suitability of the adjoining areas for housing, d the convenience of obtaining cooling water for the refinery.

As already stated a number of possible positions for an oil harbour at the western d of the bay were examined by the consulting engineers; the actual site was finally ed by bringing the dredged area as close in to the Little Aden peninsula as possible ithout having to dredge rock. Nevertheless, rock has kept the south-western limit the dredging out to a distance of 1,000 ft from the north-eastern corner of the ninsula. This north-east shore of the Little Aden peninsula consists of volcanic lls with cliffs dropping straight into the sea. It was therefore necessary at this e to form a reclaimed level area behind the oil jetties for the port buildings, pipe acks, oil tanks, roads, etc.; this reclamation also provided the quickest and cheapest ethod of disposing of the dredged material.

In the first half of 1952 the oil company's survey department carried out a check the permanently marked triangulation points previously established by the Army, r which co-ordinates were available. In addition they prepared a large-scale pographical map of the parts of Little Aden suitable for the refinery and for ousing. The points established in this survey formed the basis of all future survey ork and layout plans.

During this preliminary period in 1952 the oil company wisely sought an in- ependent opinion from the well-known firm of consulting engineers retained by the den Port Trust, who naturally have considerable experience of Aden and the cinity. This firm arranged for the hydrographic survey and the first set of borings ferred to in the Introduction. After a study of the results they expressed the pinion that the oil harbour would be better sited at the eastern, or Aden, side of awayih Bay owing to the risk of silting on the Little Aden side of the bay. Com- arisons of old surveys of the bay certainly showed changes in the sea bottom and ey gave the following reasons for expecting appreciable silting:—

(1) Silt brought down by the Wadi Kabir in spate, and littoral drift in a westerly direction.
(2) Silt brought down by the tide from the Khor Bir Ahmad.
(3) Movement of dredged material dumped from previous dredging operations, mainly during the 1939–45 war, in the western half of the bay.
(4) Other movements of the sea bottom due to tides and currents.

The oil company's consulting engineers naturally gave very careful consideration these views, and examined afresh the whole question of possible silting. They

came to the conclusion, however, that maintenance dredging at the south-western end of the bay would not be so heavy as was feared and they advised the oil company on the 28th May, 1952, that "the technical risks of adopting the site were such as might reasonably be accepted."

During the construction of the oil harbour some additional information was collected on silting but nothing has so far been observed to cause apprehension. Items which may be mentioned are:—

(1) The area of water in the bay discoloured by the silt from the Wadi Kabir was surveyed and plotted; this gave every indication that the silt tended to move eastwards away from Little Aden, and was probably deposited to the north of Aden Harbour.

(2) Periodic checks were made on the sand-banks and channel of the Khor Bir Ahmad and no indication of change was observed.

(3) Monthly surveys of the dredged areas and the surrounding sea-bed gave no indication of movement except that attributable to the dredging being carried out close by.

(4) The sea bottom was found at certain points to have a crust of cemented shell which suggested that no rapid change had taken place recently at these points.

## Layout of the Harbour

### *Weather*

The primary considerations in any harbour layout are the weather and the number of ships to be sheltered. Unfortunately, full records of winds have only recently been commenced in Aden and there were, of course, no records for Little Aden.

At Aden during the north-east monsoon from November to March the wind at night and in the early morning is light and from the north-east. During the morning it veers to east-south-east and blows from that direction during the afternoon with increased strength.

During January to March one or more spells, lasting 4 or 5 days, of winds daily exceeding 20 knots may be expected. These cause waves and swell from the east-south-east, the direction to which the harbour site in Little Aden is open, and the waves, measured at the breakwater roundhead in March 1953, were found to reach a height of 6 ft.

There appears to be considerable diversity of opinion about the direction of wind and sea during the south-west monsoon, from about mid-June to September. Most local information was that the wind was mainly south-east to south. So far as observations during the work indicated, the stronger winds recorded were mainly from the south-west, with daily maximum strengths of about 30 knots. Waves and swell from this direction on one occasion were noted to reach a height of 8 ft at Jazarat Salil; the harbour area at Little Aden was of course sheltered.

The periods April–May and September–October were mainly calm and during these periods the dredging of the approach channel was carried out.

There are records of some major storms in the Gulf of Aden, of which the cyclone of the 30th May to the 3rd June, 1885, is the most notable. The storm passed about 50 miles to the south of Aden, where it gave rise to a wind of 78 knots.

No severe storms were observed during the construction period but on the 17th July, 1951, a few weeks before the visit of the reconnaissance party, a storm from the south-west damaged an existing breakwater on the Aden side, which is open to this direction. Waves on this occasion were said to have reached a height of 10–12 ft.

When investigating the weather, the mean wind velocity for the maximum hour the day was taken as the ruling factor from the point of view of the sea and a graph wing the daily maximum hour's wind is given in Fig. 32, Plate 2. Though a gust ay have a considerable effect on a ship berthing it will not have any great effect in ilding up the sea.

*osition of breakwater*

A sketch plan of the harbour is given in Fig. 7. It shows that the harbour site open to the Gulf of Aden only from east-south-east to south, and is protected by e Little Aden peninsula from the south to the north-west, whilst from north-west east the fetch across Tawayih Bay is short.

The breakwater has therefore been sited to give protection from east-south-east south. A final decision on the position of the roundhead was not made until servations of the north-east and south-west monsoons of 1953 had been carried out.

*l requirements*

The refinery was to be built with a capacity of 5,000,000 tons per annum, all of hich would have to be imported over the jetties. Some of the refined products ill, however, be sent out by pipeline to Aden and cased goods from the future cargo erth, so that only a percentage will go out over the jetties. Bearing this in mind e oil company considered that four berths would be sufficient for their immediate quirements.

A considerable number of possible layouts for the jetties were drawn up and amined in the early stages of the design, and the final layout was settled in close -operation with the oil company. The main criterion aimed at has been ease and fety in the handling of the giant tankers inside the protected-water area. The nker berths were therefore sited to be as nearly as possible in the direction of the rongest winds, those from south-west.

*argo berth*

It was originally intended to provide a deep-water cargo berth running from the orth-east corner of the reclamation towards the turning circle. Subsequently to eal with incoming general goods and outgoing cased oil products this was re-sited ear of the oil harbour on the northern edge of the reclamation. Later it was ecided that the temporary barge berth, built to handle the incoming materials for e refinery construction, would serve as cargo berth for the present.

*ncillary berths*

A tug berth is provided to the north of the reclamation area where the tugs, while aking in fuel and water, will be well away from discharging or loading tankers and et as near as possible to their work.

A berth for a maintenance dredger is also provided, since Aden is the centre at hich the oil company consider it would be convenient to keep this craft.

For handling the British Tanker Company's stores, a wharf is provided alongside e rubble mound between the jetties and adjacent to the stores buildings.

A launch jetty is also provided, which is L-shaped and adjacent to berths 3 and 4.

*Dredging and reclamation*

The siting of the harbour was arranged to keep the dredging down to as reasonable quantity as possible, thus enabling the work to be completed in the required time;

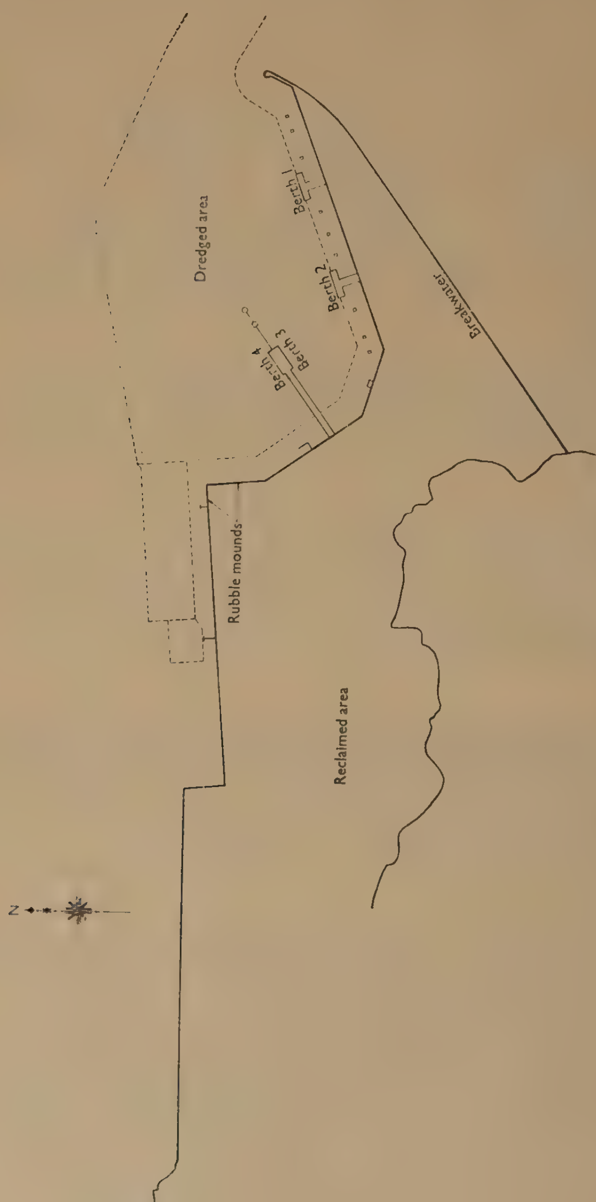


FIG. 7.—DIAGRAMMATIC REPRESENTATION OF OIL HARBOUR

Fig. 2.—Harbour from the west

Fig. 5.—Breakwater

Fig. 6.—Roundhead

Fig. 20.—Jetty steelwork berth 1

this also meant that any rock dredging had to be avoided. A few hard layers of cemented sand and shells were encountered but these were not such as to appreciably delay the work.

The harbour area was dredged to a depth of 40 ft below chart datum and was approached by a channel 7,000 ft long and 600 ft wide dredged to 38 ft. The harbour area contained a turning circle 1,600 ft in diameter. A small shallower dredged area about 1,250 ft long and 400 ft wide was later added for the future cargo berth and for the tug and dredger berths; this resulted in the total quantity to be dredged being 6,000,000 cu. yd.

A dredging tolerance of 12 in. was allowed below the bottom, increased to 2 ft, measured vertically, on the slopes.

### Design considerations

The principal factor influencing the design of the harbour was the importance of speed both in design and construction, so that a crude-oil tanker could be berthed at the earliest possible date and bring in the oil for starting up the refinery.

The necessity for speed and the difficulty in the early stages (though subsequently surmounted) of obtaining sand suitable for high-strength concrete, led to the adoption of a steel-framed jetty design with the minimum reinforced concrete.

The decision having been taken to adopt an all-welded steel-framed jetty, the consulting engineers, with the approval of the client, arranged for the contractor to be kept in close touch the whole time with all stages of the design work. During those hectic weeks when the finger jetty was being designed there was daily co-operation between the technical staff of the consultants and the contractor. The Authors, in 30 years' experience of jetty work, cannot recall any instance in which the designing team worked so closely with the building team, and for speedy construction this has now been proved a sound method. Special thanks are due to the contractor for his friendly co-operation and considerable assistance. The joint decision was made to eliminate, so far as possible, all tidal work and therefore the steel framework, besides being designed to transmit the berthing thrusts to the raker-pile clumps, was also designed to permit the driving of the raking and fender piles from the permanent work at deck level and consequently independently of the state of the tide.

Furthermore, the details of welded joints in the main framework were planned very carefully, to ensure rapid and exact assembly on site. The speed with which the jetties were subsequently erected at site reflects the very close co-operation which existed in the design. Special thanks are due to Mr Leslie Turner and his experienced steel designers who were called in to help with the great mass of detail drawings for the welded joints.

Typical of the co-operation which existed was the decision to re-design the approach steelwork leading to berths 3 and 4 using B.F.Bs, to take advantage of earlier deliveries offered by steel suppliers at that time for this type of beam. Similarly, this co-operation led to the adoption of the "stub end" principle for the jetty-head longitudinal beams. Care during detailing and checking at the design stage resulted in very few hold-ups at site and an overall saving in time as a result of speedier and easier erection than would otherwise have been the case.

So far as practicable, steel was purchased from the United Kingdom but in order to meet the construction programme some orders, principally the plate girders which form the main longitudinal and transverse members for berths 1 and 2, had to be placed on the Continent.

The key to early completion of the jetties lay in providing sheltered water for their construction by extending the breakwater out to deep water as rapidly as possible. As explained elsewhere in the Paper, surveys had shown that suitable breakwater core material would be available by opening up a quarry in the cliffs at the root of the breakwater. The special need for speed of construction led to the unusually high level of the inner core of the breakwater, as shown in Figs 3a and 3b, Plate 1. This was designed to be above high-water level so that the whole of the core could be tipped from trucks.

A second reason for speed in constructing the breakwater was to provide sheltered water behind which the dredgers would work on the main harbour dredging during the north-east and south-west monsoons. The difficulty of operating the cutter suction dredger in the swell entering the then unprotected harbour is referred to in greater detail on p. 373.

## Quarries

In the early surveys particular attention was paid to availability of suitable stone for the work, the most important item concerning the possibility of obtaining the large blocks of stone required for the armouring of the breakwater. An independent geological report was therefore obtained by the oil company.

A volcanic hill existed at the root of the breakwater and it was immediately evident that a quarry, later named quarry C, would be required at this point and that all rock for the core could be obtained here. The rock, though hard and dense, was unfortunately heavily fractured and consequently it was feared that few large blocks would be obtainable from this source.

"Wedge Hill" rising out of the level area in front of the refinery had a capping of rock capable of supplying the large blocks required. The rock was described as a soda-rich trachyte and was massive and tough. This hill was also used as the source of all crushed stone for concrete and later in the work supplied a considerable proportion of the large blocks for breakwater armour.

"White Ness" hill, at the western end of the port area, was a deposit of rock of a similar composition to Wedge Hill. The geologist's report on this was that the "felspar phenocrysts tend to be slightly larger and more platy"; this caused a tendency to break more easily and to produce more powder on crushing. Most of the rock from this hill was used in the rubble mounds and breakwater.

The contractor took out small pneumatic drills for $1\frac{1}{2}$-in.-dia. holes, drifters for $2\frac{1}{2}$-in.-dia. holes, and drills for 6-in.-dia. vertical holes, and was thus equipped for any method of quarrying which from the initial trials might prove the best. After the trials the contractor changed over entirely to quarrying by means of heading blasts, which certainly produced in a short time the large quantities of rock required.

Tables in Appendix III give a summary of the results of the various heading blasts; the overall percentage of armour, i.e., blocks exceeding 2 tons, was 24·8%. These results have also been summarized under the various quarries and confirm the original opinion formed after the reconnaissance of the site that Wedge Hill, unfortunately farthest from the breakwater, would yield the highest percentage of large stone.

## Breakwater

The breakwater is 4,126 ft long from high-water mark to the centre of the round-head, the maximum depth being 28 ft below chart datum and the maximum overall height 51 ft. The external slope is 1 in $1\frac{1}{2}$ from the sea-bed up to $-$ 1·00 level and 1 in $2\frac{3}{4}$ from that point up to the coping of the parapet at + 23·00.

For most of its length the breakwater also serves to retain the reclamation, the centre of the roundhead being only 250 ft beyond the junction of the breakwater with the rubble mound which encloses the reclaimed area.

The core of the breakwater is of broken rock from 15 lb. to 2 tons in weight and since this core was to be tipped from Euclid wagons, the top for construction was kept at + 9·25 to be above extreme high water and the construction top width was fixed at 20 ft to allow the Euclid wagons to back up quickly to the end of the tip. It is very unusual in breakwater design to bring the core up so high and, although this leads to a larger overall size, much greater speed of construction is obtained.

In the past breakwaters have been constructed largely by tipping all material, including the core, from rock trays. The faster method of tipping from trucks, developed to suit the plant available, though quicker, has the disadvantage that there is a tendency for the material to be segregated in tipping, the larger blocks of rock tending to go to the bottom, where they are not necessary, and the smaller stone remaining at the top, where it is not wanted. In order to produce an equally satisfactory result it is therefore necessary to be very particular in regard to the size of the rock when the breakwater is to be tipped.

Turning places for the construction trucks were provided by tipping out from the inside face, approximately every 300 ft. The external face was armoured with a first layer of 2–5-ton blocks and with an outer protective layer of wave-breaker blocks of 5–8 tons as shown in Fig. 3a, Plate 1. The wave-breaker blocks at the roundhead were 8–11 tons as shown in Fig. 4, Plate 1. Occasional blocks were considerably larger than those specified, one or two exceeding 20 tons. All armour to the breakwater was specified to be placed and not tipped. In this way the armour was brought up in layers and the stones were better locked together. The larger armour was placed by a Lima 2400 which lifted the blocks with a grapple and was able to reach out to the toe with the required size of block. A walkway was constructed on the jib of this machine so that the jib when lowered to a horizontal position would act as a platform from which soundings could be taken on the rock slope.

After the soundings had been taken, if there were any slack places, the Lima driver was given the number of blocks required, the chainage at which they were required, and the distance out. Marks were made inside the cab of the machine in such a way that with a 90-ft-radius setting of the jib the distance normal to the setting-out line between the centre of the machine and the rock grapple could be read off directly. This enabled the driver to bring the work up to section rapidly and accurately.

It was specified that the protective covering of blocks of the 2–5-ton category should follow not farther than 350 ft behind the front end of the core and the layer of 5–8-ton wave-breaker blocks should follow not more than 500 ft behind the core. In the event of a storm there was risk that the unprotected length of core would flatten out but some such risk was an unavoidable consequence of permitting the core to be tipped. In the construction no serious losses were incurred.

The concrete parapet consisted of a base slab 4 ft thick and a front wall with the coping at + 23·00 as shown in Figs 3, Plate 1. It was constructed in 16-ft lengths with expansion joints between each bay to allow for the settlement in the core of the breakwater which will inevitably take place in the storms of the first few years.

Before pouring the parapet concrete the layer of 2–5-ton rock immediately underneath was placed in such a way that the upper extremities of the blocks projected about 9 in. into the concrete, thus binding the concrete to the rock under it.

On the inner face of the core a seal of 12 in. of 4 in. down and 12 in. of 1½ in. down

crushed stone was placed to prevent the pumped sand of the reclamation from being washed through the coarser material in the core by waves or tides.

A berm, level with the top of the base slab of the parapet, was tipped behind the breakwater on the reclaimed area and beyond this to the roundhead the base slab was widened to 20 ft. In this way sufficient width is provided for a crane or other traffic to travel down on the base slab and carry out any necessary future maintenance including the replacement of any blocks, should they be displaced by a heavy sea.

The concrete of the roundhead was 58 ft outside diameter and the base slab was 6 ft thick. The roundhead before the placing of the final 8–11-ton blocks is shown in Fig. 6, facing p, 355.

## Rubble mounds

The rubble mounds to retain the reclamation have a total length of 9,250 ft and were designed to be entirely tipped from Euclids. The core was therefore brought up to + 9·00 and was sufficiently wide for the Euclids to back down to the end. Turning places were tipped on the inside every 300 ft.

The core was of rock 2 lb. to ¼ ton in weight and blocks up to 2 tons were permitted if not adjacent to the inner face. An armour coat of blocks ¼ ton to 2 tons was tipped on the external face following fairly closely behind the core. After the mounds had been joined up, Euclids running on the + 9·00 level tipped the rock up to the finished level of + 13·00. A cross-section of a typical rubble mound is shown in Fig. 8.

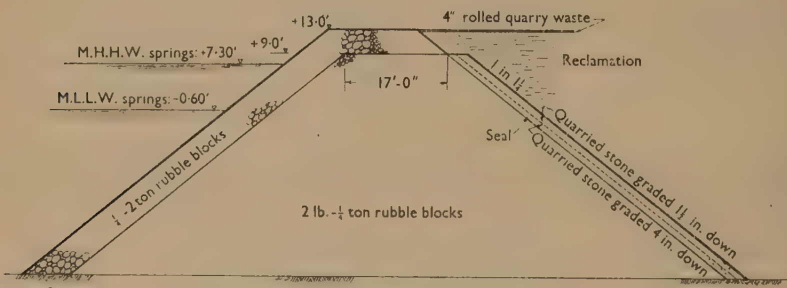


Fig. 8.—Typical section of rubble mound

A seal of 12 in. of 4-in.-down and 12 in. of 1½-in.-down crushed stone was placed on the inner face to contain the pumped material.

## Tanker berths

There are four tanker berths, two being single T-headed jetties, and the remaining two being sited on either side of a finger jetty. The jetty head in each case is 250 ft long and all four berthing faces are similar, plans and sections being shown in Figs 9 and 10, Plate 1, and Figs 11 and 12, Plate 2.

Tanker berths 1 and 2 each consist of a jetty head with combined road and pipeway approach, the approach being sufficiently long to bring the berthing face out to the area dredged to 40 ft. Nine isolated mooring dolphins for these two berths are provided to take the ships' ropes.

Tanker berths 3 and 4 consist of a jetty head with berthing faces on each side and a combined road and pipeway approach. Four mooring dolphins are provided, two inshore of the jetty head in the approach and two offshore of the jetty head and connected to it by a light footway.

The jetties are supported on hexagonal steel piles, specially designed for rolling in two pieces and shop welding together longitudinally. Because of the number required for this and other jetties it was possible to obtain them by cutting special rolls to form an economical design. The weight per foot is 117·75 lb. and the modulus on the two axes is 151·75 and 125·82 inch units.

All piles were sand-blasted and coated with three coats of Wailes Dove No. 50, one in the shop and two on the site before driving; the piles were filled internally with concrete after driving.

## Test piles

Three test piles were driven, one in the centre of each of berths 1 and 2 and one adjacent to berths 3 and 4. Since berths 3 and 4 were the first to be constructed the test pile in this vicinity was driven first. Four piles were driven round it to support the load and a fifth to act as a reference pile from which the settlements were recorded.

This test pile failed at $1\frac{1}{2}$ times the working load. Unfortunately it was tested at a period when the sea was not calm and with the load approximately 56 ft above the sea bottom it was not possible to brace the piles sufficiently rigidly to prevent all movement. In consequence the slight movement caused by the sea undoubtedly facilitated failure by preventing the full sea-bed friction from developing.

The test piles in berths 1 and 2 carried a test load of double the working load without appreciable settlement.

Time/settlement curves for the tests are given in Figs 13–18.

## Pile driving

Pile driving commenced, using floating plant, on the approach to berths 3 and 4, and in this approach and in more than half the length of the jetty head the piles reached the required set at approximately the designed level, i.e., 30 ft of penetration into the sea-bed. Thereafter the piles had to be lengthened since no satisfactory set could be obtained on higher lying beds of cemented sand. The upper bed had thinned out and the piles were presumably penetrating it and continuing down to the next bed. When driving of the raking piles was first commenced no effective set was obtained. A raking pile after pitching must have a small deflexion under its own weight and as a result of this deflexion it will tend to vibrate during driving. It is thought that this movement of the pile kept the sand, which was of rounded grains mostly of one size, on the move and so prevented the development of skin friction. It was found that after 48 hours the piles hardened up and by going back and re-testing them a satisfactory set could be obtained. A maximum length of 112 ft was therefore fixed for these rakers.

It was specified that, after driving the vertical piles, temporary bracing should be attached so that the piles could be pulled into position and held rigidly while they were filled with concrete, the caps put on, and the main framework welded to the caps. Octagonal capping plates were used, 3 ft across flats, with a central hole for grouting-up the pile; these caps permitted a certain amount of tolerance in order to assist in the rapid erection of the steelwork. The vertical piles were specified to be not more than 6 in. out of position after driving before pulling into position, and not

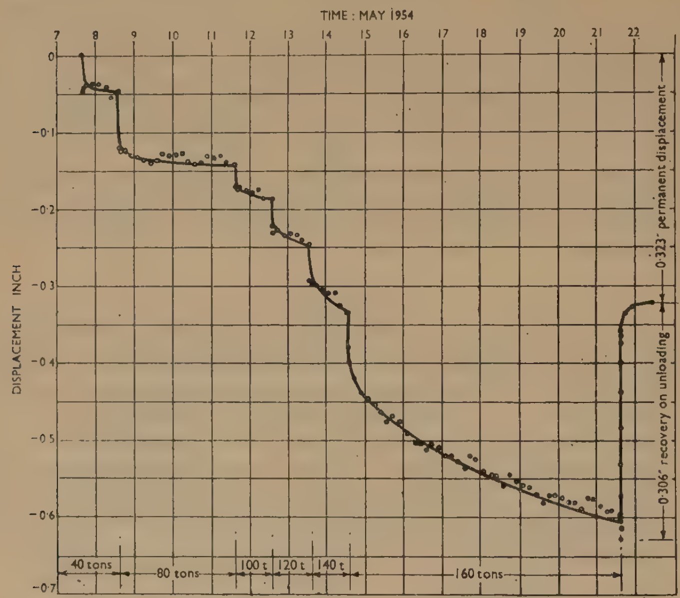


FIG. 13.—GROSS DISPLACEMENT/TIME CURVE FOR COMPRESSION TEST ON TEST PILE NO. 1

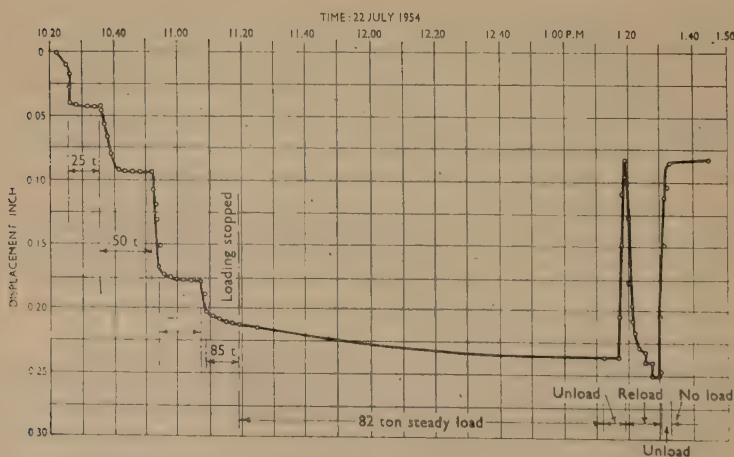


FIG. 14.—GROSS DISPLACEMENT/TIME CURVE FOR TENSION TEST ON TEST PILE NO. 1

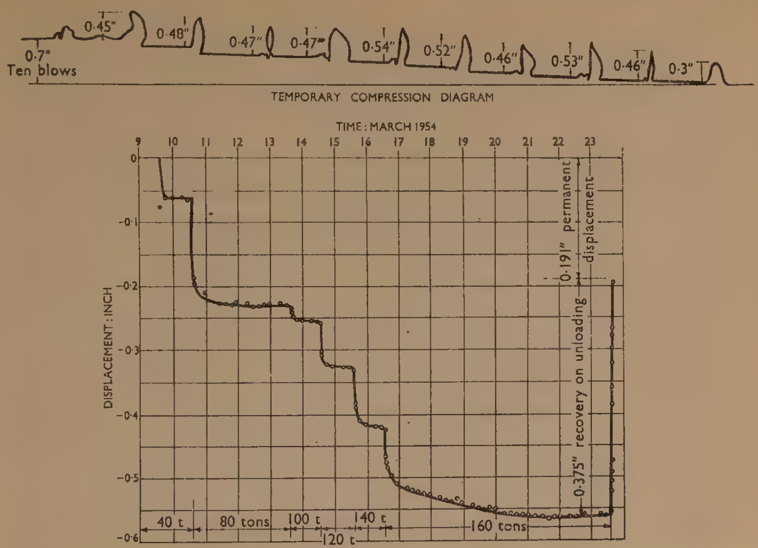


FIG. 15.—GROSS DISPLACEMENT/TIME CURVE FOR COMPRESSION TEST ON TEST PILE NO. 2

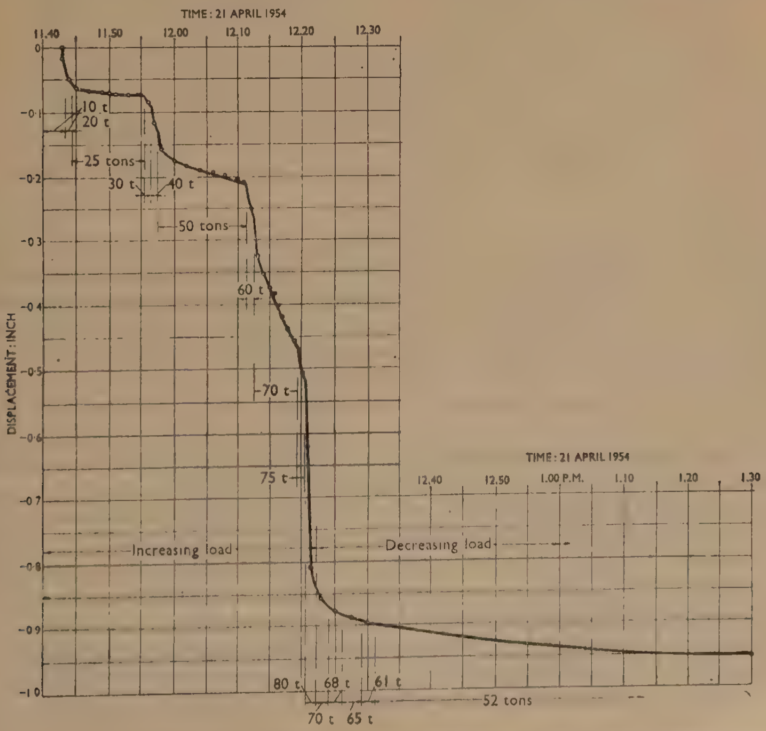


FIG. 16.—GROSS DISPLACEMENT/TIME CURVE FOR TENSION TEST ON TEST PILE NO. 2

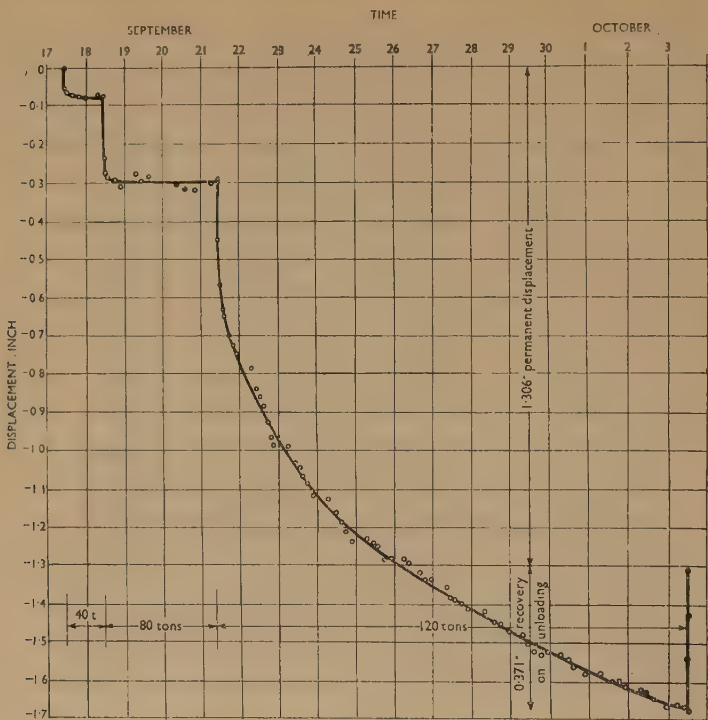


Fig. 17.—Gross displacement/time curve for compression test on test pile no. 3

more than $1\frac{1}{2}$ in. when pulled and ready for filling with concrete and for attaching the steel framework.

## Steelwork

All joints in the steel framework of the tanker berths were welded, including the scarfing of the piles; this resulted in a considerable quantity of site welding. Particular care was taken in the design to arrange that almost all of this welding was down-hand. Stub ends of the longitudinal B.F.Bs were shop-welded on to the transverse beams to allow the longitudinal beams to be connected to the transverse members on site by means of a simple down-hand weld. Typical joints are shown in Fig. 19.

The steel framework of the jetties is immediately below deck level and was designed to avoid all tide work in its construction; only a small amount of tide work was necessary in connexion with the fenders. The transverse beams were built-up girders 3 ft deep and on the ends of these the buffer-plate girders carrying the rubber blocks are situated. A general view of the steelwork in berth 1 is shown in Fig. 20.

Lateral strength is given to the jetty by raking piles, of similar hexagonal section to the vertical piles, driven in groups of four and connected to each other and to the framework by reinforced concrete pile caps shown in Fig. 21, facing p. 370.

Since some of the welded joints were rather complicated, a model was made of a typical joint. The model could be taken to pieces and the welding sequence

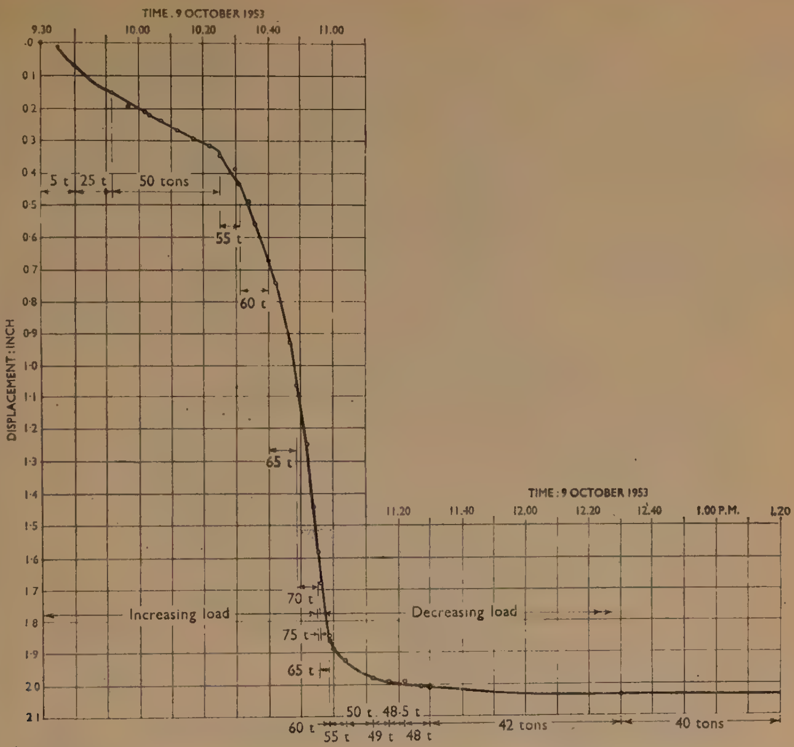


Fig. 18.—Gross displacement/time curve for tension test on test pile no. 3

followed. It was photographed in stages corresponding to the proposed order of erection, the welding to be carried out at each stage being clearly marked on the photographs. These photographs and the proposed erection procedure—the result of many conferences with the contractor—were forwarded to the site. The model itself followed, and was made available at the jetty for all to see.

All welders underwent a test before being allowed on permanent work, tests being arranged to conform with the work to be carried out. Subsequently welders were kept on the type of work in which they had been tested.

Gamma radiographic examination of butt welds was carried out at site and the Table in Appendix IV gives the numbers of joints and the radiographs taken. A magnetic crack-detector was also used to search for surface cracks on fillet welds.

Very few joints which passed the visual inspection were subsequently found to be defective. Naturally the difficult places where flaws were considered more likely were selected for photographing. However, the upper portion of the web in the butt joints of the main transverse girders was the only place where cracks were found, though some of the early seal runs were unsatisfactory; all these were cut out and re-welded and steps taken to avoid a recurrence. The small amount of poor welding shows that the time and trouble spent in designing the steelwork so that almost all welds were down-hand was well spent.

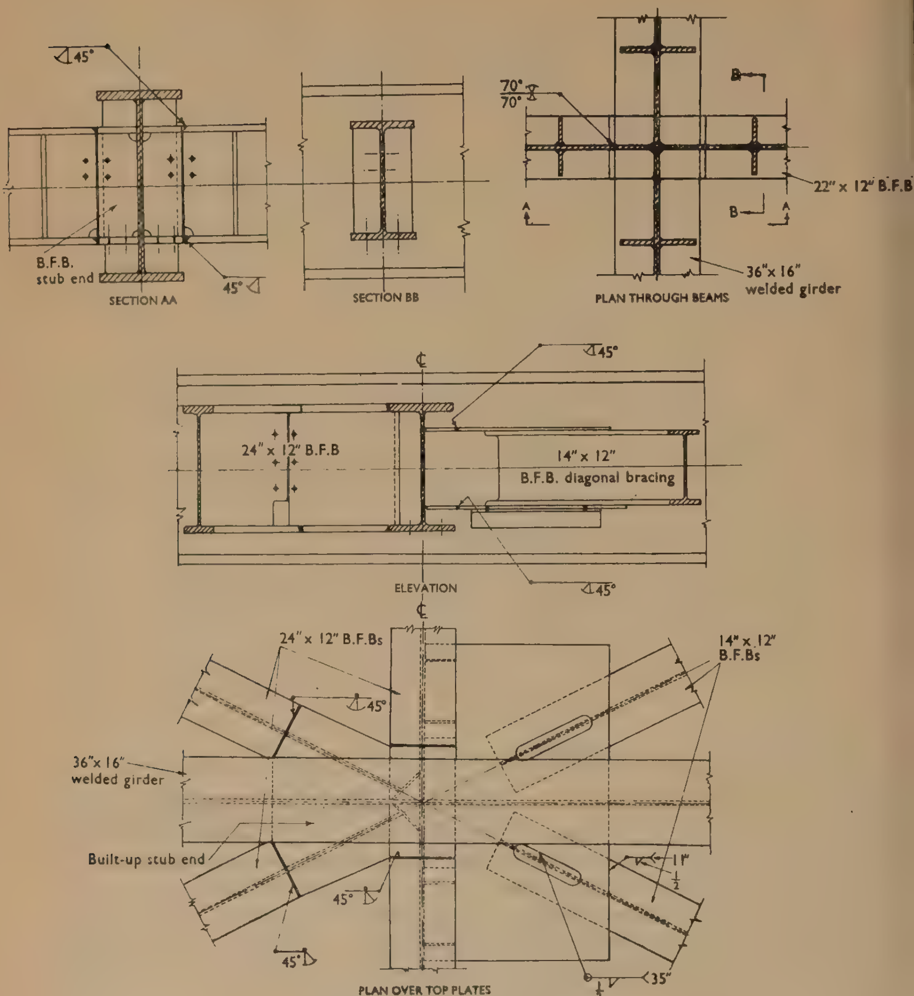


FIG. 19.—TYPICAL WELDED JOINTS

The source used for the gamma rays was iridium 192 and Ilford Industrial X-Ray "C" film was used. The film was held in cassettes between lead screens, the whole being kept in position by magnets. Lead numerals fixed by plasticine recorded the number of the radiograph and other particulars of the weld and joint. The apparatus was attached by clips to the beam near the joint radiographed.

When the main transverse girders, longitudinal girders, and some bracing in each bay had been welded in position a second pile frame was travelled on them to drive the raking piles.

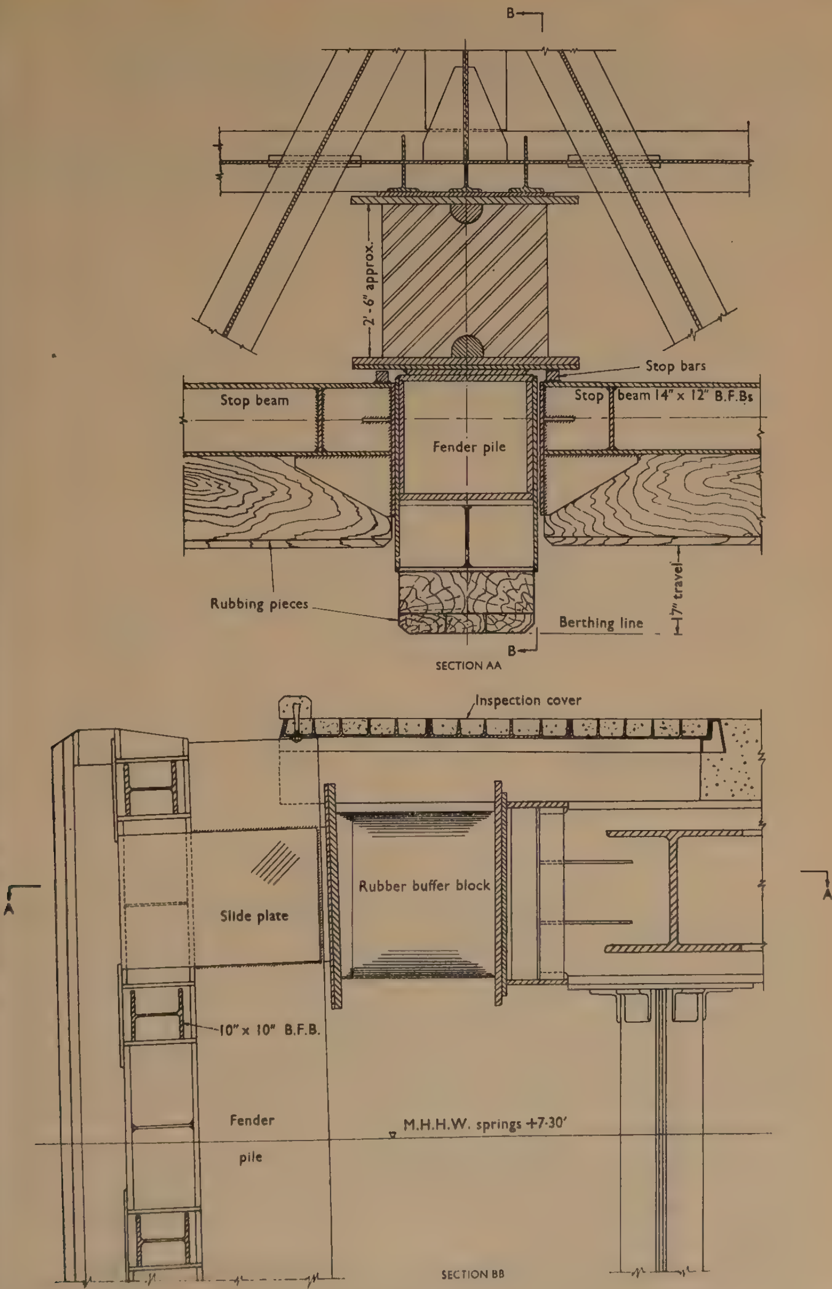


FIG. 23.—SECTION SHOWING RUBBER BLOCK MOUNTING

## Fenders

Twelve fender piles were provided to each berth, two groups of four on the face at 165-ft centres and a pair at each end angled at 12½° to the berthing face.

The fender system was designed to deal with the forces expected from the normal berthing of a 32,000-ton tanker.

Each fender pile is restrained at its head by plates on either side between which it slides and is free only to move inwards, compressing the rubber block; the designed

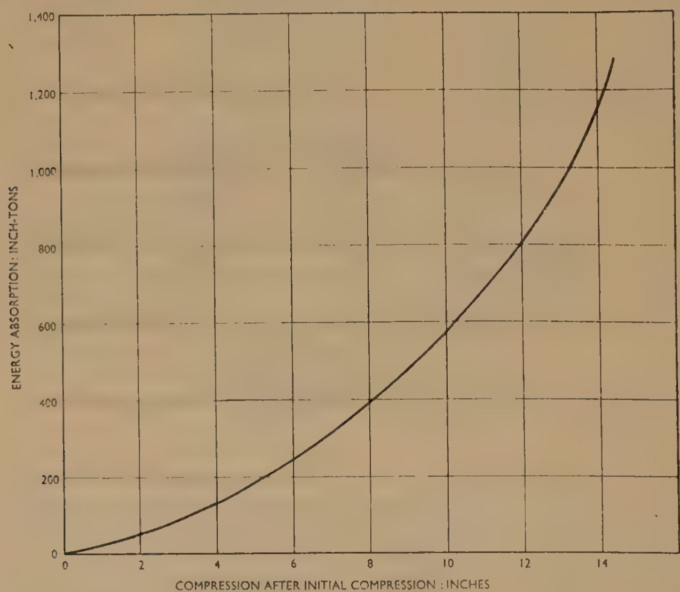


Fig. 25.—Fender blocks

travel is 15 in. Forces parallel to the jetty are transmitted through the side plates directly to the framework. Fig. 22 shows the stop beam and side plates.

The rubber blocks are 32 in. dia. × 32 in. long and each was tested at the manufacturer's works to ascertain the energy absorption. At 50% compression the mean energy absorption per block was 1,169 in.-tons, the maximum 1,330, and the minimum 1,020; at 60% compression the mean was 2,069 in.-tons, the maximum 2,300, and the minimum 1,820. A section through a rubber block is given in Fig. 23 and the blocks are shown in Fig. 24, facing p. 371. A curve of the energy absorption against compression for the mean block is shown in Fig. 25.

The blocks were given an initial compression of 2 in. to keep the fender pile pressed against the stop and avoid continual movement in a choppy sea. When compressed a further 15 in. inwards or to a total of 53%, the mean block would absorb 1,360 in.-tons.

The fender piles, Fig. 26, Plate 2, were built up of M.S. plates and sections, the upper end being 2 ft 2 in. × 2 ft 0¾ in., tapering to 2 ft 2 in. × 1 ft 4½ in. at the bottom, and were driven to an outward batter of 1 in 43. After driving, the lower

TABLE 1.—BERTHINGS

| Berthing No. | Gross displacement: tons | Velocity of approach: ft/sec | End to touch first | $\frac{WV^2}{2g}$: in.-tons | Energy taken by fenders: in.-tons | % | Maximum measured in single fender: % |
|---|---|---|---|---|---|---|---|
| Berth 3 | | | | | | | |
| 9 | 24,750 | 0·20 | Bow | 184 | 165 | 90 | 70 |
| 11 | 20,500 | 0·25 | Stern | 238 | 175 | 74 | 55 |
| 25 | 20,500 | 0·25 | Bow | 238 | 180 | 76 | 48 |
| 41 | 37,000 | 0·17 | ,, | 200 | 190 | 95 | 70 |
| 43 | 42,500 | 0·29 | ,, | 668 | 725 | 109* | 72 |
| 50 | 24,300 | 0·25 | ,, | 283 | 180 | 64 | 49 |
| 57 | 42,400 | 0·48 | Stern | 1,820 | 700 | 38 | 18 |
| 75 | 39,800 | 0·31 | ,, | 713 | 400 | 56 | 38 |
| Silverbrook | 23,000 | 0·50 | Bow | 1,070 | 1,130 | 105* | 27 |
| Berth 4 | | | | | | | |
| 2 | 17,000 | 0·50 | Stern | 792 | 285 | 36 | 18 |
| 10 | 19,790 | 0·47 | Bow | 816 | 282 | 35 | 10 |
| 42 | 21,800 | 0·75 | ,, | 2,280 | 782 | 34 | 25 |
| 46 | 41,750 | 0·56 | Stern | 2,436 | 1,660 | 68 | 40 |
| 52 | 37,000 | 0·62 | ,, | 2,650 | 995 | 38 | 20 |
| Nicholas | 24,000 | 0·61 | Bow | 1,665 | 1,615 | 97 | 46 |

* A small error has presumably been made in the velocity measurement.

portions of the fender piles were filled with a bituminous compound, so that their flexibility would be unimpaired, and the upper portions with concrete.

Tell-tale rods, attached to the tops of the fender piles, enabled the maximum compression of each block to be measured after each berthing.

In the case of most of the early berthings the ship's speed parallel to the jetty was reduced to an insignificant amount, so that the velocity of the vessel was at right-angles to the jetty. Observations were taken of the velocity of approach and fender deflexion but insufficient have so far been recorded on which to base definite conclusions. Table 1 gives details of the berthings where the ship's velocity was sufficient to give appreciable deflexion of the fender piles.

There are irregularities in the readings in Table 1 as must be expected, since the ship's velocity is measured immediately preceding the impact and it may be accelerating or stopping. Furthermore the tug may be pushing or pulling, thus adding to or subtracting from the blow.

Timber walings fastened to 10 in. × 10 in. B.F.Bs are provided between fender piles to make a flush face for longitudinal movement of the ship; these walings fit into sockets on the fender piles so as not to restrict the flexibility of the latter. A general view of the fender assembly is given in Fig. 27.

### Deck

The concrete deck slopes back from the berthing face at a slope of 1 in 100 so that any oil spilt on the deck can be washed back into the slop tank.

Precast concrete slabs were placed on the transverse girders, thus acting as soffit shuttering and at the same time containing the bottom reinforcement and forming part of the deck slab. They were of considerable assistance in expediting the deck concreting.

### Mooring dolphins

Nine isolated dolphins were constructed to take the ropes from ships lying at berths 1 and 2. They were of two types, six having one bollard and three having two bollards to permit use by ships at berths 1 and 2 at the same time.

The dolphins consist of a concrete slab supported on hexagonal steel piles driven vertically. Similar piles, driven to a rake of 1 in 3 from the centre, were provided to take the pull on the bollard.

Construction of the dolphins was to follow this sequence of operations:—

(1) Drive vertical piles.
(2) Cast concrete pile caps on them.
(3) Place precast concrete beams and slabs between piles.
(4) Cast concrete slab leaving a hole in the centre.
(5) With the pile frame on this concrete drive the raking piles through the hole in the centre.
(6) Weld reinforcing rods across central hole.
(7) Concrete up central hole.

Dolphins C and D at the seaward end of the finger jetty were constructed in a similar manner; details of the latter are shown in Fig. 28.

### Ancillary berths

The tug berth was a T-head jetty with head 43 ft × 22 ft and with a mooring dolphin on either side. Hexagonal steel piles as for the main berths were used, with

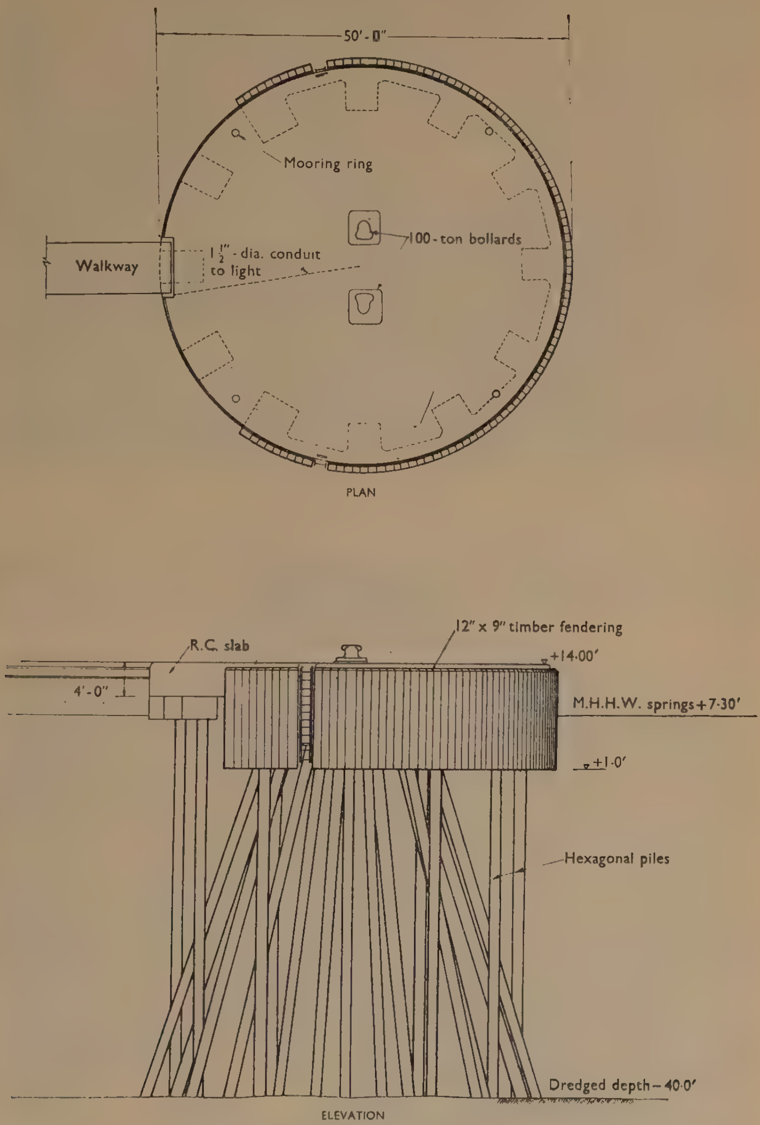


FIG. 28.—DOLPHIN D

a steel frame and a concrete deck. The dolphins were each of four piles connected by a concrete slab and joined to the jetty by a walkway.

A similar type of construction was adopted for the berth for the maintenance dredger except that the deck was of timber.

The stores wharf was of steel-framed all-welded construction on hexagonal piles and was 62 ft 6 in. long × 48 ft wide. It was provided with a 5-ton hand derrick.

The launch jetty was of B.F.B. piles with a concrete deck and had a head 80 ft × 11 ft. A canopy 14 ft wide was provided along the back to shelter craft.

### Painting

Because of the high temperature and the salt atmosphere, steel corrodes quickly in Aden and consequently great care was taken to plan its protection. Steelwork generally was specified to be sand-blasted and painted one coat Wailes-Dove No. 50 before shipment. Where this was damaged in shipment the corroded portions were sand-blasted and touched up and then the whole was given two further coats. It was found, however, that the finished thickness of the Wailes-Dove was rarely greater than 0·02 in., which was less than had been anticipated. The temperature in the sun, at the time when the painting took place, was usually about 125°F; out of the sun the steel pile cooled quickly and became damp. At this high temperature it was found difficult to put on a thicker even coat. When coupled up and tested, however, in preparation for cathodic protection, the resistance of the pile coating was found to be satisfactory. Marine growth on the surface of the piles was rapid, the piles quickly becoming coated with weed and barnacles. Considerable thought had been given in the design to the use of a hot-applied enamel paint, but this was rejected since it would have been more difficult and therefore slower. A thicker coating could, however, have been obtained by this means.

### Fire-fighting water intake

A channel for salt water to the fire pumps was constructed in sheet-piling and was 10 ft wide, with bottom at — 16·00. To avoid delaying the main construction, a short length of the rubble mound at this point was constructed first with small stone only; this was subsequently grabbed out, and the sheet-piling driven in the gap. The bottom of the intake channel was covered with precast concrete blocks, the gaps between these and the sheet-piling being filled with bagged concrete. A screen at the outer end keeps out driftwood.

### Concrete

High-quality concrete was required for the jetty decks and pile caps and for the decks of the dolphins, the total quantity being about 12,500 cu. yd. Mass concrete for the breakwater and other small items brought the total up to 27,750 cu. yd.

The only sand readily available on site was the wind-blown dune-sand from the desert; a sieve test of this showed that 97% would pass a 25-mesh sieve. There was also a high shell content and even the site at Little Aden finally selected for the best dune-sand yielded sand with 25% of shell; in other areas the sand contained as much as 50% of shell.

The "flour" in the crushed stone aggregate still further increased the percentage of fine material, so that special measures had to be taken to produce suitable sand for the concrete for the jetty decks and dolphins. If a dense concrete was not obtained for these, deterioration might result.

FIG. 21.—TYPICAL RAKER PILE CAP

FIG. 22.—STOP BEAM

Fig. 24.—Rubber block

Fig. 27.—Face of berth showing fenders

Two steps were taken to produce the required density. First a Symonds V screen was installed to remove particles below 25 mesh from the crushed sand, and secondly, from the Wadi Kabir bed, sand was obtained free from shell and with a slightly better grading. The screened crusher and Wadi Kabir sands were batched in equal proportions (see Appendix V) and a reasonably satisfactory grading resulted, as shown in the curve in Figs 29 and 30. This made a far more workable concrete.

Another feature of the concrete was the rapid setting of the cement as a result of the high temperature. Tests were carried out of setting time against temperature, and the results are shown in Fig. 31.

Batching was carried out by the contractors for the refinery, who installed a water-cooler to keep the temperature of wet concrete below 92°F.

The various mixes used and a summary of the results of testing 784 cubes are given in Appendix V.

### Cathodic protection

Cathodic protection is provided for all piles in the jetties and dolphins. The necessary power is supplied from the refinery power station and the anode consists of a line of carbon rods sunk into the sand of the reclamation. The cathodic protection was designed independently by Mr K. A. Spencer, an expert in this work.

Temporary cathodic protection was applied to the finger jetty, berths 3 and 4, to prevent corrosion before the permanent transformer-rectifiers were installed.

### Port buildings, etc.

The following port buildings were erected:—

(1) A jetty-end galley for berths 3 and 4 and one for berths 1 and 2, situated conveniently for the berths they serve.
(2) A fire station near the fire-pump house, not far from the root of berths 3 and 4.
(3) A hose store.
(4) Buildings and a yard for the British Tanker Company's stores.
(5) An anemometer house complete with anemometer. This was erected temporarily near point C of the rubble mound and was subsequently moved to a position near berth 1.
(6) A tide gauge was installed on berth 1.

### Dredging and reclamation

The dredging amounted to approximately 6,000,000 cu. yd, the material consisting mainly of fine sand, mostly passing a 25 sieve, with a large percentage of shells. In some areas layers of sand, with or without shell, had been naturally cemented together and these were appreciably harder to dredge. Though the output of the bucket dredgers was not very much reduced when dredging this cemented material, lumps were stopped by the screen of the stone box of the reclamation dredger and the box had then to be opened and cleared. The time taken for this operation was such that any material containing an appreciable percentage of the lumps had to be considered "unpumpable" and arrangements were made to dump this to sea.

A 50-ft berm was allowed from the toe of the rubble mound to the top of the dredged slope and all slopes at the perimeter of the dredging were designed as 1 in 5. Dredging

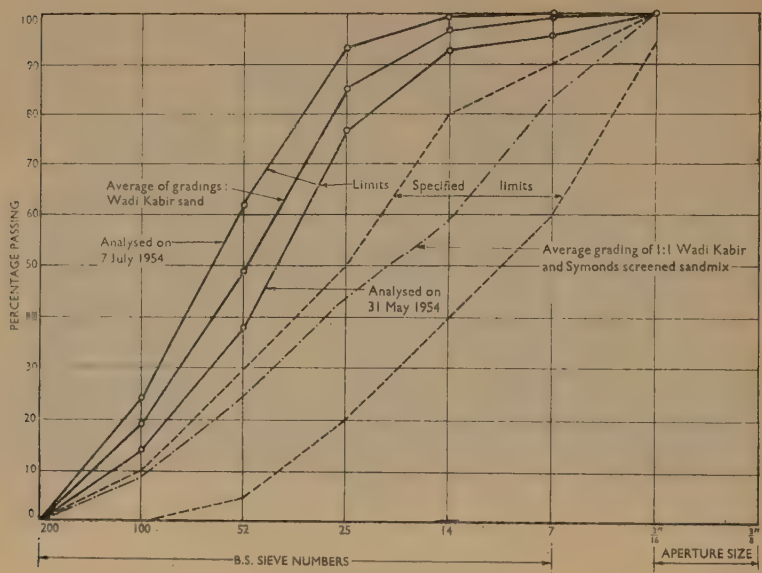


Fig. 29.—Sand gradings

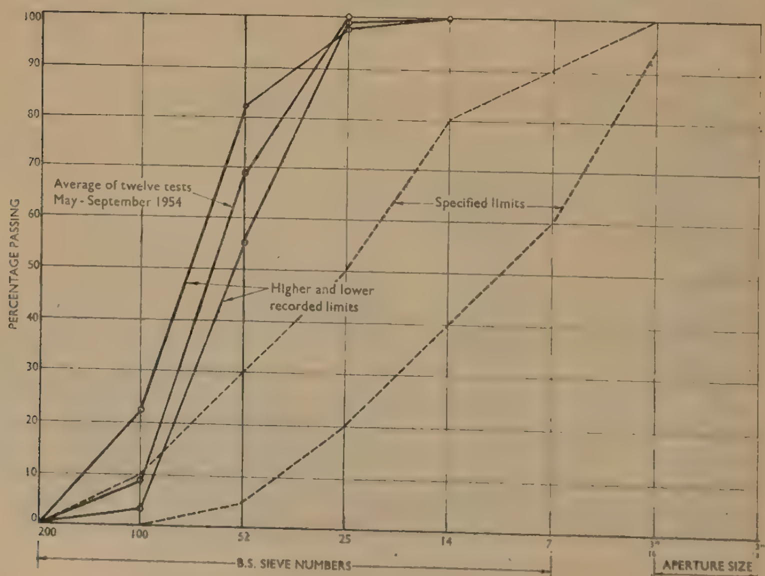


Fig. 30.—Sand gradings: sample: dune sand

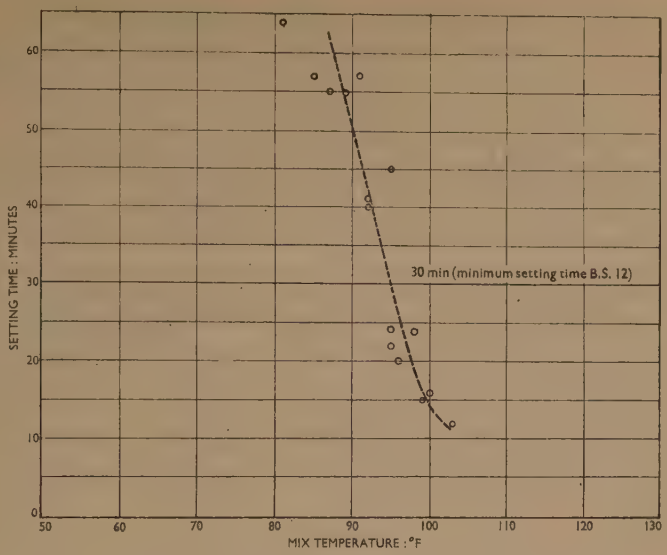


FIG. 31.—CEMENT SETTING TIMES. VARYING MIX TEMPERATURES

for the slopes was carried out in steps, as is normal, the sand falling to a slope afterwards. Sections taken at the end of the construction period showed slopes between 1 in 3 and 1 in 5; nowhere was a slope flatter than 1 in 5 observed.

The contractor for the dredging commenced work with one cutter suction dredger, one bucket dredger, one reclamation dredger, and ancillary plant. Under the contract it was, however, provided that the position would be reviewed after 4 months' work and an additional dredger and reclamation unit brought out unless progress showed that was unnecessary.

The cutter suction dredger, though capable of a very high output, was unsuccessful for two main reasons. First, because it was held in position by spuds working through a rotating table. The spuds were dropped alternately and the drum rotated to give a steady forward movement of the dredger. The spuds, however, were at the rear of the dredger and consequently stood in the area dredged. They acted as long cantilevers which had to hold the dredger against the swell coming into the then unprotected area, consequently they fractured just below the rotating table. Secondly, the powerful cutter on the dredger stirred up the sand of the sea bottom causing a considerable amount of silting in the previous cut.

Owing to weather delays and the trouble with the cutter suction dredger, progress in the early stages was not sufficient to permit any reduction in the plant and the joint contractors were instructed that the additional plant would be necessary. They then decided to bring out two additional bucket dredgers and to convert the cutter suction dredger on the site to pump the material ashore. A list of the final plant is given in Appendix II.

Under the contract earlier completion dates had been fixed for the dredging of certain areas to permit the pile driving for the jetties to commence. It was also possible to dredge the approach channel only during the periods April–May and

September–October when, at the change of the monsoon, calm weather might be expected. The weather was not very propitious in April–May 1953, but in any case progress of the main dredging did not then permit of dredgers being spared for this work. It was therefore fortunate that a long calm spell occurred in September–October 1953; advantage of this was taken by moving all three dredgers into the channel, thus enabling almost the whole of the channel to be dredged.

Despite the early difficulties the whole of the dredging of the harbour as originally envisaged was completed 7 weeks ahead of the contract time.

During the reclamation precautions were taken to prevent damage to the crushed-stone seal behind the rubble mounds. This was done by holding steel plates, simulating groynes, running out from the rubble mound and thus depositing the sand without washing away the seal. Pumping was also so carried out that the coarser material was so far as possible deposited immediately behind the mound.

With the exception of the "unpumpable" material all the dredging was pumped ashore; the pumped sand contained only a small proportion of silt and made very satisfactory filling. Two test plates, each 12 in. square, were buried soon after an early part of the reclamation had been pumped up to level. One plate was kept unloaded and no settlement whatever was recorded; the second test plate was loaded with 2 tons of steel and settled $\frac{3}{16}$ in. in $10\frac{1}{2}$ weeks. The depth of filling at this point was 22·5 ft.

The reclamation area was about 240 acres in extent and the open areas were surfaced with 4 in. of quarry waste to prevent the sand blowing.

The marine survey, both before and after the work, was by echo sounder, the dry paper type of machine being used. Since the sea was often dead calm in the morning accurate results could be obtained by this method. Sections were also taken of the slopes in front of the rubble mounds by hand lead since it was not possible to do this type of work with the echo sounder.

One complication in connexion with the dredging was an ammunition dump at the outer end of the approach channel. On one occasion when the box to prevent stones from entering the pump of one of the reclamation dredgers was opened it was found to contain forty bombs and shells, all containing explosives, but fortunately without detonators! After some qualms and additional insurance cover the whole area was dredged without incident.

## Living conditions

The contractor for the harbour commenced by chartering a ship to accommodate his staff. This enabled work to begin before the hutted camp was ready for occupation.

After the initial stages, housing and feeding for everyone on the site was carried out by the American-British Consortium responsible for the refinery. A very high standard was maintained throughout and all Europeans ate and slept in air-conditioned buildings; food in the messes was of a high quality. It is considered that this materially assisted progress and reduced the sickness rate.

In addition, the contractor for the refinery published a weekly newspaper, constructed a swimming enclosure and an open-air cinema to hold 750, and provided other recreational facilities, thus catering for leisure hours of the employees in a place which would otherwise have been barren in this respect.

During the months October to April working conditions were good and the hot-weather conditions did not prevent men doing a good day's work. In July and

August, during the south-west monsoon, blowing sand was rather trying, the wind usually getting up at about 10.30 in the morning, when outside operations such as the welding in the pile yard often had to cease.

### Contract

In view of the urgency of the work and the contractor being given the go-ahead at the same time as the consultants responsible for the design, there was no alternative but to adopt a "target" type of contract. There is no doubt that it was only by the adoption of this type of contract that the work was completed in the required time.

Exceptional speed, however, always costs extra money, and most clients prefer the normal schedule of rates contract, placed as a result of tenders based on a schedule of approximate quantities.

The broad principles of the contract for the oil harbour were agreed and the contract was signed on the 15th December, 1952, the contract time being 108 weeks. At this date there were in existence no schedules of quantities whatever. It was therefore laid down in the contract that the target price (known as the approved estimated value) should be agreed within 6 months of commencement. It was found, however, that more time was needed to get out and price the many schedules of quantities, and the target was not agreed until the 1st December, 1953.

The contract contained a useful combined bonus system whereby the contractor would earn a bonus for every week of completion ahead of contract time, with the further proviso that he would also receive 25% of any saving, i.e. 25% of the amount by which the actual cost of the work was less than the target. For this purpose a revised target value has had to be calculated which is obtained directly from the agreed estimated value by adding or subtracting, at the target rates, for increases or decreases in the quantities of the various kinds of work. The contract laid down that the maximum bonus which could be earned by any combination of time saving and cost saving should not exceed 50% of the fixed fee. In the same way the maximum penalty from late completion and excess cost was also limited to 50% of the fixed fee. The fixed fee was defined in the contract as a fixed percentage of the approved estimated value.

The target type of contract is therefore seen as a prime-cost-plus-fixed-fee system with the addition of an incentive to the contractor for speed and economy. The disadvantage is that the incentive disappears if there are so many unexpected difficulties that the work takes considerably longer than anticipated and the actual costs greatly exceed the target. This did not occur, however. The work was certified as substantially complete 13 weeks ahead of the contract date, and the actual cost has proved less than the revised target value.

Clearly it would have been more satisfactory if the original target figure could have been agreed before the contract was signed, but this would have delayed the starting date until all the schedules of quantities had been taken out. The oil company were not prepared to accept this delay. In return for their large expenditure they have obtained a 5,000,000-ton-per-annum refinery with a protected four-berth harbour which was brought into use 20 months after commencement; they are believed to be well satisfied.

### Completion time

The visit to the site on the 14th July, 1952, represents the date on which detailed planning and design could begin and the 15th November, 1952, was fixed as the

date of commencement of Wimpey's harbour contract. The order to the dredging contractors to commence work was given on the 21st November, 1952.

The dredging contractors completed the dredging of the harbour area on the 10th July, 1954, and the first tanker was berthed alongside berth 3 on the 17th July, 1954.

The harbour was certified substantially complete on the 10th September, 1954, 95 weeks after the commencing date and 13 weeks ahead of the contract time.

A progress diagram for the work is given in Fig. 33, Plate 2.

## ACKNOWLEDGEMENTS

The thanks of the Authors are due to the British Petroleum Company, for whom the works were constructed, for permission to present this Paper, and to their representatives at the site, the Aden Petroleum Refinery Ltd and their Resident Engineer, Mr R. H. Sheldrake, for considerable assistance during the works.

They would like to thank the contractor for the harbour work, George Wimpey & Co. Ltd, and the joint dredging contractors (the Dredging and Construction Company and K. L. Kalis Sons and Company) for the co-operative manner in which they carried out their contract.

Special thanks are due to Mr Spearing, Mr Banks, Mr Adey, and Mr Ray of the oil company's "Refineries Department" for their continued help and encouragement.

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## APPENDIX I

### LIST OF PERSONS CONCERNED WITH THE CONSTRUCTION

*Aden Petroleum Refinery Ltd*

General Manager: A. W. G. Trantor
Resident Engineer: R. Hedley Sheldrake
Chief Engineer: G. A. Malone
Project Accountant: C. B. Fratson
Personnel Manager: L. H. Baxter

*George Wimpey & Co. Ltd*

Project Manager: A. W. Coutts
Deputy Project Manager: P. Hogan
Administrative Manager: V. S. Kilmartin
Chief Engineer: E. J. Fraser
Sub-Agent—Jetties: C. S. Findlay
Site Manager: R. Mitchell

*The Joint Companies Dredging and Construction Ltd and K. L. Kalis Sons & Co. Ltd*

Agent: N. P. Kapteyn

*Rendel, Palmer & Tritton*

Resident Engineer: H. Scrutton
Deputy Resident Engineer, E. N. Robertson
Quantity Surveyor: J. T. Sinclair
Asst. Quantity Surveyor: T. Lucas
Senior Asst. Engineer: G. Alexander
Hydrographic Surveyor: J. R. Brogan
Asst. Engineers: D. N. Oliphant; E. D. Walcot; P. R. H. Kelley; P. J. Haugh; R. R. Cooper
Drawing Office: D. J. Bateman

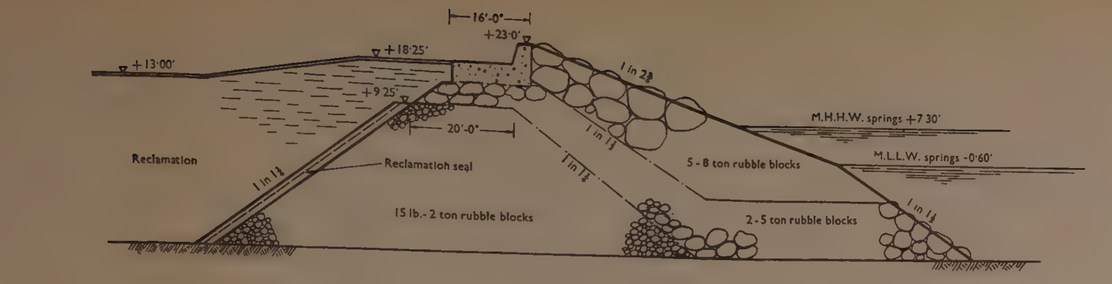


FIG. 3a.—GENERAL CROSS-SECTION OF BREAKWATER

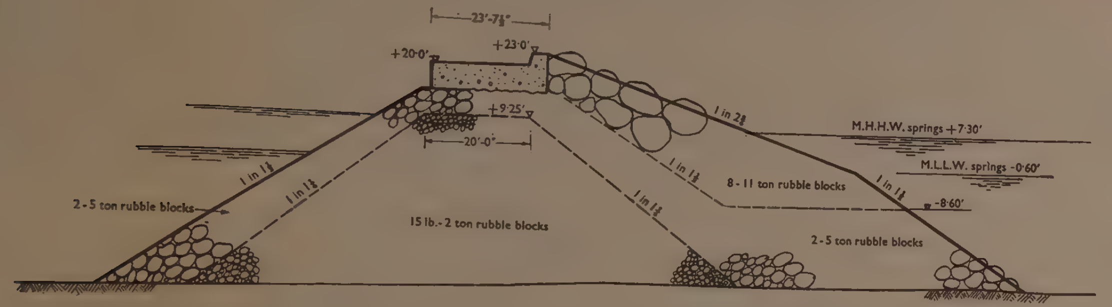


FIG. 3b.—CROSS-SECTION OF BREAKWATER NEAR ROUNDHEAD

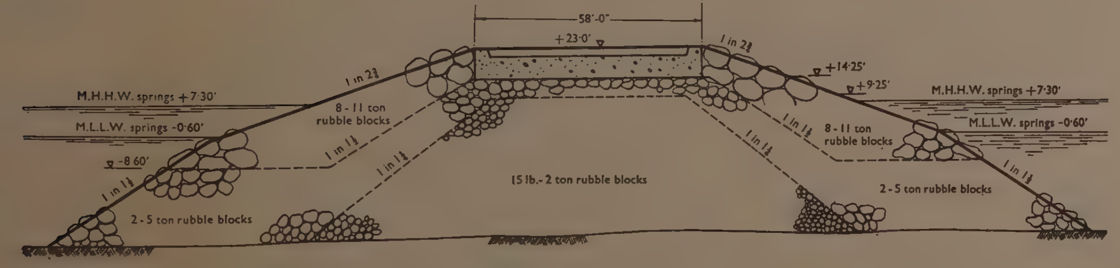


FIG. 4.—SECTION THROUGH ROUNDHEAD

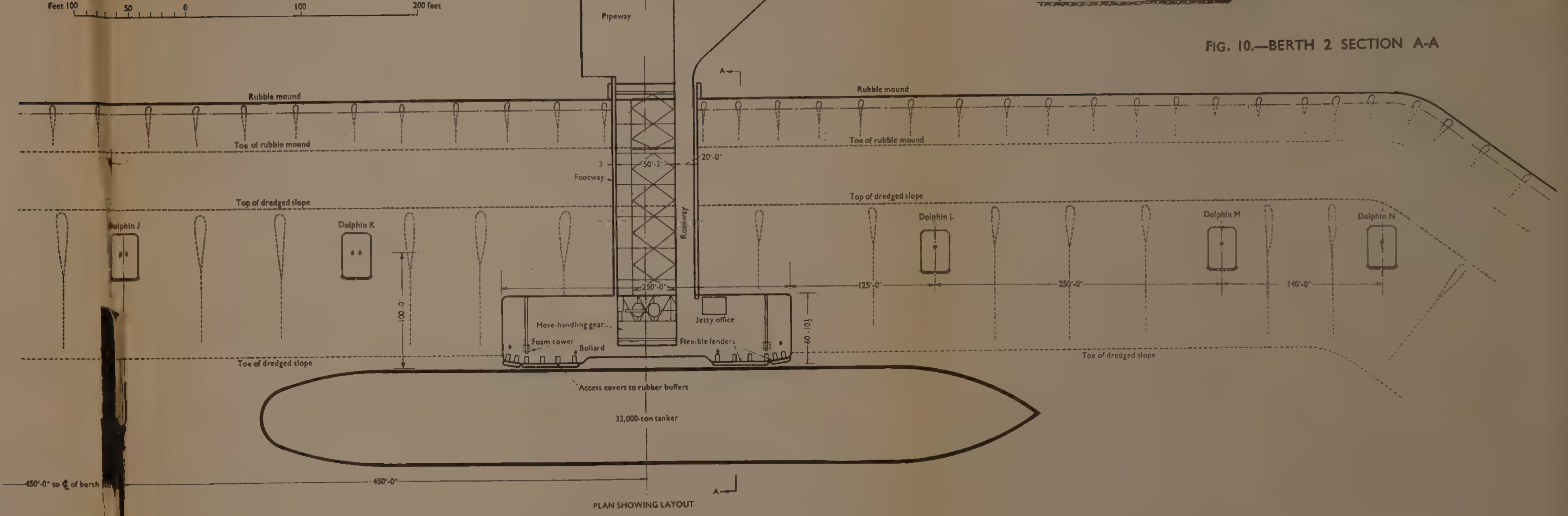


FIG. 9.—BERTH 2 (BERTH 1 IS SIMILAR)

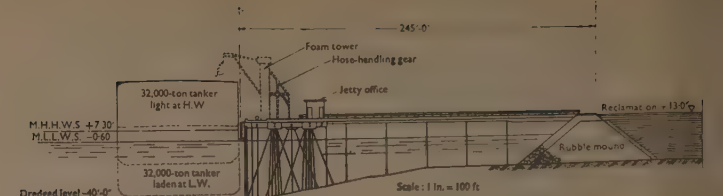


FIG. 10.—BERTH 2 SECTION A-A



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HAROLD SCRUTTON

William Clowes & Sons, Limited: London

# THE DESIGN AND CONSTRUCTION OF ADEN OIL HARBOUR

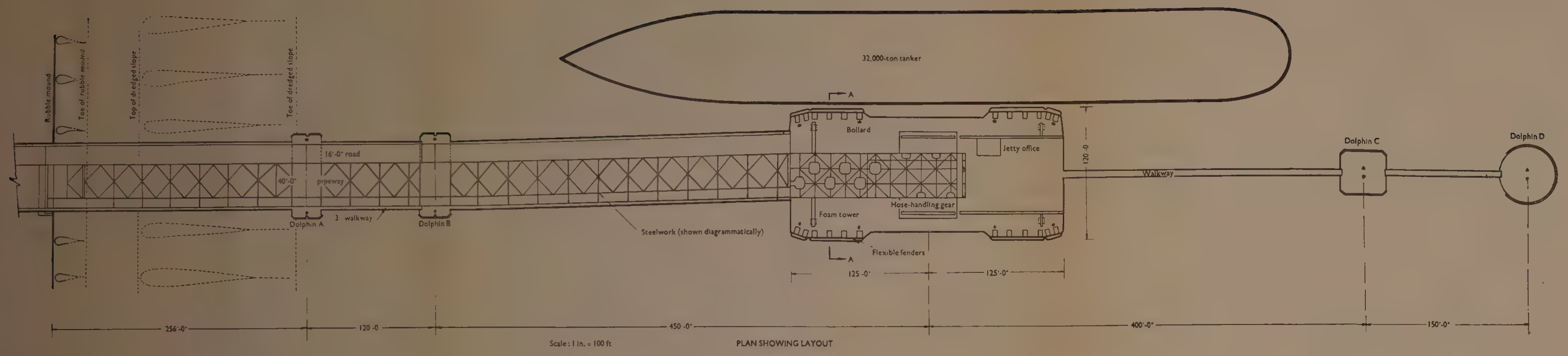


FIG. 11.—BERTHS 3 AND 4

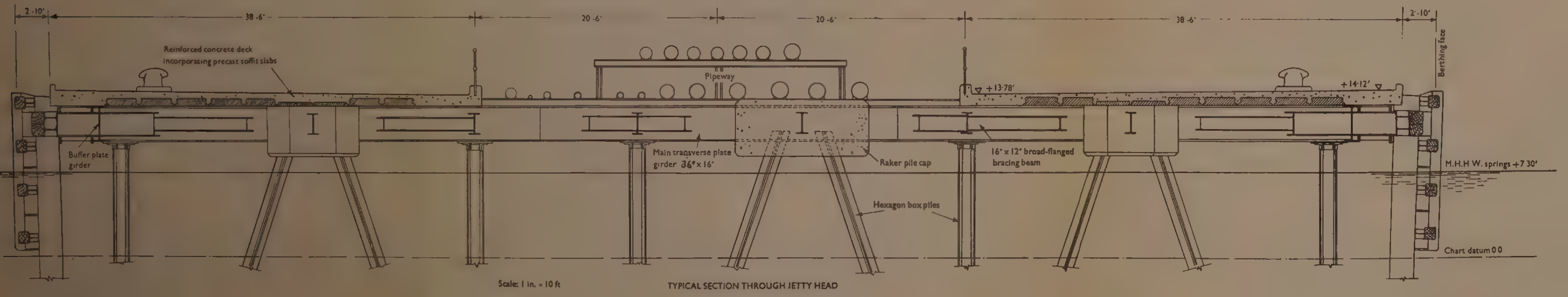


FIG. 12.—BERTHS 3 AND 4

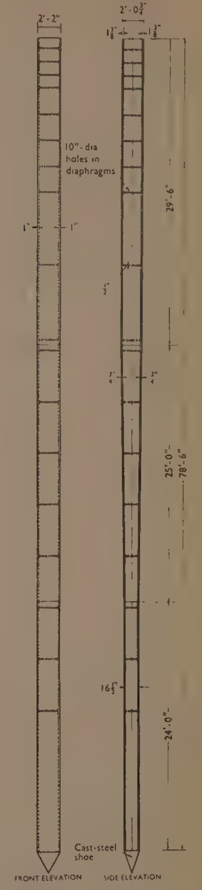


FIG. 26.—FENDER PILE

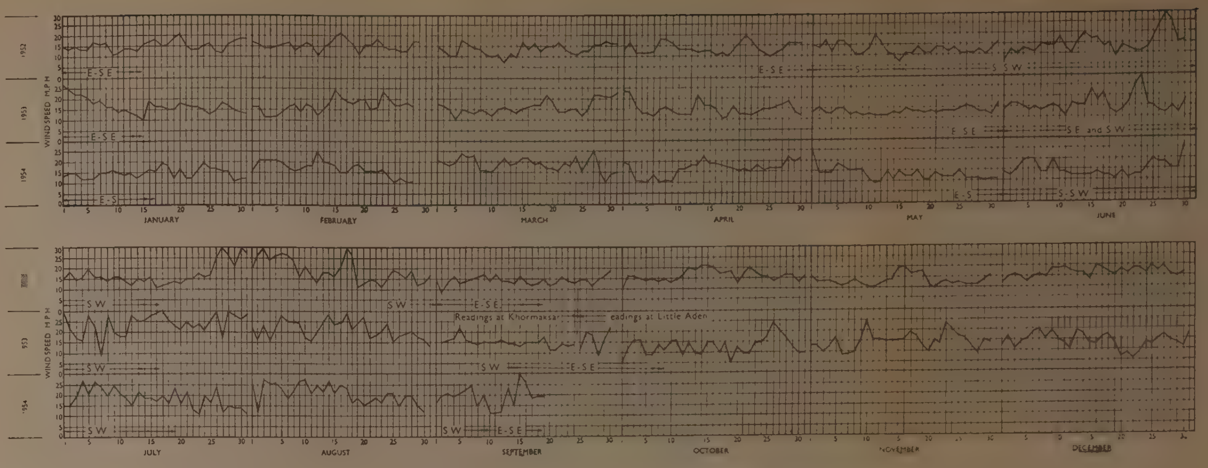


FIG. 32.—WIND VELOCITY DIAGRAM (MAXIMUM HOUR DAILY)

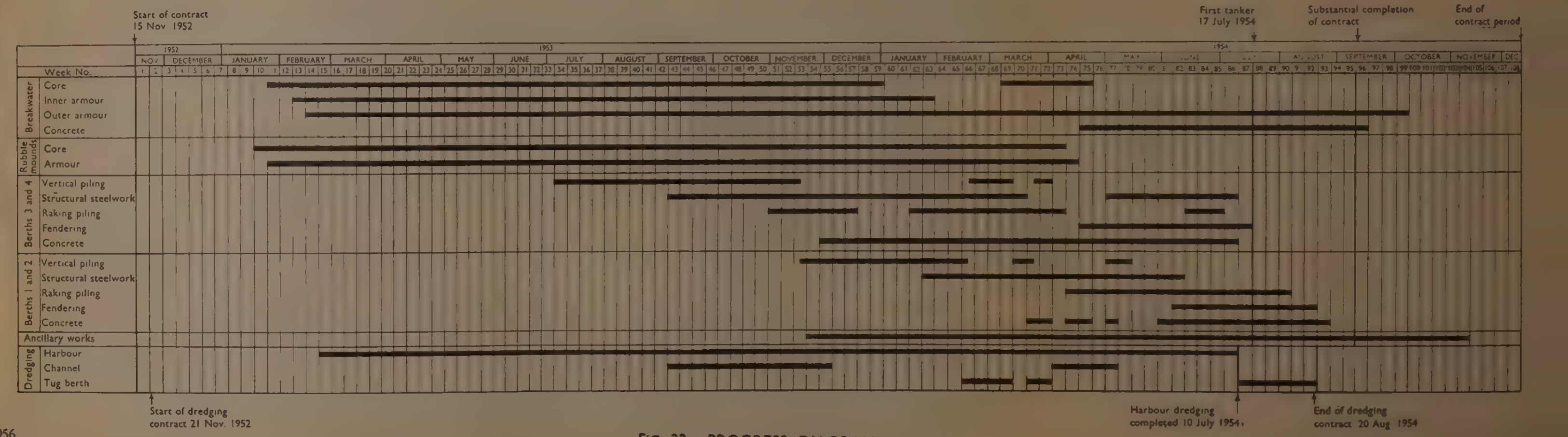


FIG. 33.—PROGRESS DIAGRAM

J. E. G. PALMER and
HAROLD SCRUTTON



WILLIAM CLOWES & SONS, LIMITED: LONDON

## APPENDIX II

### MAIN ITEMS OF PLANT USED

*Excavators*

One 2400 Lima and equipment
Five 1201 Lima and equipment
Six 802 Lima and equipment
One 19RB and equipment
Two 304 NCK equipment

*Mobile cranes*

One 12½-ton Coles crane
Two 6-ton Coles cranes
One 3-ton Hydrocrane

*Derrick cranes*

Two 10-ton Morgan derricks and bogies
Two 5-ton Morgan derricks and bogies
One 7-ton Henderson derrick on a pontoon
One 5-ton Anderson derrick and bogies

When all jetties were in progress five of these derricks were mounted on barges.

*Tractors and trailers*

Six D8 tractors and bulldozers
One 55L Fiat tractor and bulldozer
Three Ferguson tractors
Two 80-ton H.D. tractors and low-loader
Two Scammels
One 40/60-ton "Crane" trailer
One 20/30-ton "Rozers" trailer
Three 3-ton Ferguson trailers

*Scrapers*

Three 12-cu. yd scrapers

*Graders*

Six 101 Galion graders

*Drills, compressors and equipment*

Seven 500-cu. ft C.P. compressors*
Three 315-cu. ft C.P. compressors*
Two 210-cu. ft C.P. compressors*
One 6-tool Broomwade compressor*
Four 10-ft × 4-ft C.P. air receivers
Four 6-ft × 3-ft C.P. air receivers
Four 27-ton rock drills
Five wagon drills

* Including rock drills, feed legs, etc.

*Concrete mixers*

Six 12S Rex mixers
One Moonraker hoist
Two cement guns
Five 14-cu. ft weighbatchers
One 20-cu. ft junior weighbatcher

*Road Rollers*

One 10-ton Aveling-Barford roller
One 10-ton Marshall roller
One 11-wheel R.T. roller
One sheepsfoot roller

*Euclids*

Twenty-four rear-dump Euclid wagons
Seven rock-carrier Euclid wagons

*Welding sets*

Forty-four Lincoln arc-welding sets
Eighteen Murex welding sets

*Generators*

- Four 80-kW generators
- Two 25-kW generators
- Thirteen 20-kW generators
- Four 15-kW generators
- One 10-kW generator
- Seven lighting towers

*Piling equipment*

- One 65-ft raking pileframe and equipment
- One 50-ft pileframe and equipment
- One 50-ft pileframe and equipment
- One M.R.27 Menck pileframe and equipment
- Three 9B3 McKiernan-Terry hammers
- One 54-ft × 37-ft × 7-ft pontoon
- One 3-ton drop hammer

*Pumps*

- Six 4-in. jetting pumps
- Four 4-in. Sykes pumps
- Two 4-in. trailer pumps

*Conveyors*

- One Loband conveyor
- One 40-ft Hiloveyor
- One 30-ft "M"-type conveyor

*Shop equipment*

- One 0350 milling machine
- One 8½-in. lathe
- One radial drill
- One 36-in. saw bench
- One 42-in. Coburn wheeling and raising machine
- Two surfacing and thicknessing machines
- One Tecalemit compressor
- Two sets Lima jacks

*Miscellaneous plant*

- One 24-in. × 18-in. crushing and screening machine
- One Acrow bar-bending machine
- One K30 three-tine rooter

*Transport*

- Six Fordson E.T.6 tippers
- Fourteen Commer tippers
- Two Commer lubrication units
- Seven Leyland T/Us
- Two Bedford buses
- Six 800-gal water tankers
- Two 1,000-gal fuel tankers
- Four Bedford P/Us
- One Commer P/U
- Twenty-six Land Rovers
- Two Humber Super Snipe cars
- Nine Humber Hawk cars
- Eight Hillman station wagons
- Seven B.T.C. bus trailers
- Five flat-bed trailers
- Two low-bed trailers
- One A.E.C. Matador wrecker truck
- Four pipe trailers

*Floating plant*

- Two motor lifeboats
- Two fast launches
- Two towing launches
- Six 100-ton barges
- Five 400-ton barges
- One light-duty tug
- One 500-h.p. tug

*Dredging plant*

- Three 28-cu. ft bucket dredgers
- One 26-in. reclamation dredger
- One 24-in. reclamation dredger
- Two 300-b.h.p. tugs
- Two 180-b.h.p. tugs
- One floating workshop
- Eight 800-cu.-yd reclamation barges
- One echo-sounding launch
- One water tanker
- One oil-fuel tanker
- Three launches
- Three bottom-opening barges

## APPENDIX III

### HEADING BLASTS

TABLE 2.—QUARRY C

| Heading No. | 2–8-ton armour: tons | Core: tons | Roads, etc: tons | Total | Tons/lb. |
|---|---|---|---|---|---|
| 2 | 4,740 | 15,130 | 2,520 | 22,390 | 4·8 |
| 9 | 1,320 | 5,690 | 1,960 | 8,970 | 4·0 |
| 17 | 3,700 | 10,360 | 3,550 | 17,610 | 6·5 |
| 10 | 1,110 | 9,090 | 7,250 | 17,450 | 3·9 |
| 11 | 1,760 | 18,440 | 6,460 | 26,660 | 5·03 |
| 23 and 28 | 3,750 | 15,130 | 6,060 | 24,940 | 5·65 |
| 30 | 5,880 | 15,350 | 6,480 | 27,710 | 6·59 |
| 39 | 5,190 | 21,890 | 9,000 | 36,080 | 4·8 |
| 42 | 9,320 | 24,860 | 17,820 | 52,000 | 4·7 |
| 45 and 48 | 11,660 | 30,880 | 14,330 | 56,870 | 5·1 |
| 47 and 52 | 10,530 | 37,920 | 22,010 | 70,460 | 5·1 |
| 53 and 61 | 9,580 | 2,050 | 17,990 | 29,620 | 5·6 |
| 56 | 3,610 | 680 | 7,400 | 11,690 | 5·1 |
| 65 | 2,340 | 4,910 | 1,090 | 8,340 | 4·7 |
| 66 | 8,610 | 13,950 | 17,480 | 40,040 | 5·0 |
| 67 | 2,430 | 1,470 | 10,735 | 14,635 | 2·3 |
| 71 and 73 | 11,565 | — | 55,275 | 66,840 | 5·6 |
| | 97,095 | 227,800 | 207,410 | 532,305 | |
| | 18·3% | 42·7% | 39% | | |

TABLE 3.—WEDGE HILL

| Heading No. | 2–8-ton armour: tons | Core: tons | Roads, etc: tons | Total | Tons/lb. |
|---|---|---|---|---|---|
| To 24/8/53 | 18,490 | 36,030 | 520 | 55,040 | — (part of blast) |
| No. 49 | 8,320 | 13,910 | 2,880 | 25,110 | 5·1 |
| 51 and 55 | 20,080 | 5,090 | 19,660 | 44,830 | 5·3 |
| 57 and 58 | 4,670 | — | 9,180 | 13,850 | 5·0 |
| 59 and 60 | 11,160 | 1,900 | 12,820 | 25,880 | 5·0 |
| 43 | 3,860 | 6,550 | 980 | 11,390 | 2·9 |
| 64 | 10,485 | 16,560 | 7,985 | 35,030 | 6·2 |
| 69 | 6,620 | — | 2,420 | 9,040 | 4·5 |
| 68 | 10,065 | 650 | 8,640 | 19,355 | 3·2 |
| 72 | 9,010 | — | 7,830 | 16,840 | 3·6 |
| 74 | 3,135 | — | 5,135 | 8,270 | 3·0 |
| 78 | 1,715 | — | 3,595 | 5,310 | 5·3 |
| 81 and 82 | 5,075 | — | 6,360 | 11,435 | 5·2 |
| | 112,685 | 80,690 | 88,005 | 281,380 | |
| | 40% | 28·7% | 31·3% | | |

TABLE 4.—WHITE NESS

| Heading No. | 2–8-ton armour: tons | Core: tons | Roads, etc: tons | Total | Tons/lb. |
|---|---|---|---|---|---|
| 3 | 2,510 | 7,100 | 10 | 9,620 | 3·5 |
| 4 and 6 | 17,670 | 26,990 | 1,110 | 45,770 | 5·3 |
| 13 and 15 | 21,580 | 38,580 | 7,610 | 67,770 | 5·2 |
| 16 | 3,520 | 11,320 | 3,810 | 18,650 | 4·0 |
| 27 | 6,270 | 27,550 | 7,290 | 41,110 | 4·0 |
| 44 | 9,810 | 23,700 | 2,690 | 36,200 | 6·2 |
| 52A | 1,750 | 7,020 | 3,510 | 12,280 | 3·8 |
| | 63,110 | 142,260 | 26,030 | 231,400 | |
| | 27·2% | 61·5% | 11·3% | | |

TABLE 5.—OTHERS

| Headings | 2–8-ton armour: tons | Core: tons | Roads, etc: tons | Total | Tons/lb. |
|---|---|---|---|---|---|
| Prospect Pt Nos 14 and 19 . . . | 9,620 | 30,430 | 12,240 | 52,290 | 3·5 |
| Prospect Pt Nos 24, 25, and 26 . . | 16,350 | 58,995 | 33,810 | 109,155 | 4·0 |
| Shore Rock No. 18 | 1,370 | 5,860 | 940 | 8,170 | 3·0 |
| Shore Rock No. 5 . | 4,050 | 6,160 | 720 | 10,930 | 7·3 |
| Prospect Pt No. 718 | 7,870 | 25,440 | 2,770 | 36,080 | 6·4 |
| | 39,260 | 126,885 | 50,480 | 216,625 | |
| | 18·1% | 58·6% | 23·3% | | |

TABLE 6.—SUMMARY

| Heading No. | 2–8-ton armour: tons | Core: tons | Roads, etc: tons | Total |
|---|---|---|---|---|
| White Ness . . . | 63,110 | 142,260 | 26,030 | 231,400 |
| Quarry C . . . . | 97,095 | 227,800 | 207,410 | 532,305 |
| Wedge Hill . . . | 112,685 | 80,690 | 88,005 | 281,380 |
| Others . . . . . | 39,260 | 126,885 | 50,480 | 216,625 |
| | 312,150 | 577,635 | 371,925 | 1,261,710 |
| | 24·8% | 45·7%* | 29·5% | |

* In the latter stages of the work the core of the breakwater and rubble mounds was complete and no further small rock was required.

## APPENDIX IV

### WELDED JOINTS: RADIOGRAPHS

| | No. of joints | No. of joints radio-graphed | Total radio-graphs | Repairs radio-graphed |
|---|---|---|---|---|
| Berth 1 | | | | |
| *Jetty head:—* | | | | |
| Built-up girder straight butts | 21 | 15 | 64 | 4 |
| Built-up girder right-angle butts | 142 | 21 | 51 | — |
| B.F.B. right-angle butts | 42 | 2 | 3 | — |
| B.F.B. diagonal-bracing butts | 120 | 12 | 12 | — |
| B.F.B. diagonal-bracing gussets | 136 | — | — | — |
| Fender group butts | 82 | — | — | — |
| Pile caps | 72 | — | — | — |
| *Approach:* miscellaneous | — | — | 9 | — |
| | 615 | 50 | 139 | 4 |
| Berth 2 | | | | |
| *Jetty head:—* | | | | |
| Built-up girder straight butts | 21 | 13 | 47 | 1 |
| Built-up girder right-angle butts | 142 | 8 | 20 | — |
| B.F.B. right-angle butts | 42 | 2 | 4 | — |
| B.F.B. diagonal-bracing butts | 120 | 8 | 8 | — |
| B.F.B. diagonal-bracing gussets | 136 | — | — | — |
| Fender group butts | 82 | — | — | — |
| Pile caps | 72 | — | — | — |
| *Approach:* miscellaneous | — | 4 | 5 | — |
| | 615 | 35 | 84 | 1 |
| Berths 3 and 4 | | | | |
| *Jetty head:—* | | | | |
| Built-up girder straight butts | 44 | 12 | 29 | — |
| Built-up girder right-angle butts | 24 | 2 | 5 | — |
| B.F.B. right-angle butts | 304 | 2 | 6 | — |
| B.F.B. diagonal-bracing butts | 116 | 4 | 6 | 2 |
| B.F.B. diagonal-bracing gussets | 246 | — | — | — |
| Fender group butts | 164 | 3 | 11 | — |
| Pile caps | 116 | — | — | — |
| Fixed-fender frames | — | 6 | 8 | — |
| *Approach* | — | — | — | — |
| | 1,014 | 29 | 65 | 2 |
| Pile yard | | | | |
| Pile splices | — | 9 | 36 | — |

## APPENDIX V

### CONCRETE: MIXES

Five qualities of concrete were used in the work, A, D, E, F, and B/W mix No. 4. These were further divided to allow the use of different overall gradings to suit the aggregate and mixing conditions available.

The concrete mixes used were as follows:—

| Quality A | A |
|---|---|
| Cement | 2,240 lb. |
| Dune sand | 1,708 „ |
| $\frac{3}{16}$-in. minus crusher sand | 3,400 „ |
| $\frac{3}{4}$-in. aggregate | 2,368 „ |
| $1\frac{1}{2}$-in. aggregate | 4,720 „ |

| Quality D | D1 | D2 | D3 | D4 |
|---|---|---|---|---|
| Cement | Not used | Not used | 3,640 lb. | Not used |
| Wadi sand | | | 1,820 „ | |
| $\frac{3}{16}$-in. minus crusher sand | | | — | |
| Symonds sand | | | 1,820 „ | |
| $\frac{3}{4}$-in. aggregate | | | 7,280 „ | |

| Quality E | E1 | E2 | E3 | E4 |
|---|---|---|---|---|
| Cement | Not used | 224 lb. | 2,656 lb. | 224 lb. |
| Wadi sand | | 140 „ | 2,250 „ | 215 „ |
| $\frac{3}{16}$-in. minus crusher sand | | 280 „ | — | — |
| Symonds sand | | — | 2,250 „ | 215 „ |
| $\frac{3}{4}$-in. aggregate | | 290 „ | 7,520 „ | 600 „ |

| Quality F | F1 | F2 | F3 | F4 |
|---|---|---|---|---|
| Cement | 224 lb. | 224 lb. | 2,240 lb. | 224 lb. |
| Wadi sand | 128 „ | 171 „ | 2,475 „ | 280 „ |
| $\frac{3}{16}$-in. minus crusher sand | 386 „ | 342 „ | — | — |
| Symonds sand | — | — | 2,475 „ | 280 „ |
| $\frac{3}{4}$-in. aggregate | 718 „ | 718 „ | 7,360 „ | 675 „ |

B/W Mix No. 4—Bechtel concrete with $\frac{3}{4}$-in. aggregate.

B/W mix No. 4 was used solely for bridges 1 and 2.
Mix A was used for the breakwater and for concrete hearting to hexagonal steel piles.
Mix D3 was used for raker-pile caps.
Mix E was used for decks to jetties and precast work.
Mix F was used for abutments to jetty approaches and in all dolphin decks.

### SUMMARY OF RESULTS OF CONCRETE CUBE TESTS

| Quality | | 4 days | 7 days | 28 days |
|---|---|---|---|---|
| A | Number of cubes tested | — | 32 | 62 |
| | Mean crushing strength, lb/sq. in. | — | 4,293 | 5,263 |
| | Minimum crushing strength, lb/sq. in. | — | 2,110 | 4,136 |
| | Standard deviation | — | 953 | 667 |
| D3 | Number of cubes tested | — | 21 | 37 |
| | Mean crushing strength, lb/sq. in. | — | 4,860 | 6,366 |
| | Minimum crushing strength, lb/sq. in. | — | 2,751 | 4,890 |
| | Standard deviation | — | 830 | 723 |
| | Percentage below specified strength | — | 9·5 | Nil |
| E2 | Number of cubes tested | 67 | 26 | 164 |
| | Mean crushing strength, lb/sq. in. | 3,950 | 4,521 | 6,055 |
| | Minimum crushing strength, lb/sq. in. | 2,675 | 2,830 | 3,638 |
| | Standard deviation | 735 | 814 | 786 |
| | Percentage below specified strength | — | Nil | 1·2 |
| E3 | Number of cubes tested | 7 | 41 | 99 |
| | Mean crushing strength, lb/sq. in. | 3,872 | 3,948 | 5,405 |
| | Minimum crushing strength, lb/sq. in. | 3,079 | 2,347 | 3,700 |
| | Standard deviation | — | 702 | 703 |
| | Percentage below specified strength | — | 2·4 | 2 |

| | | 4 days | 7 days | 28 days |
|---|---|---|---|---|
| E4 | Number of cubes tested | — | 6 | 22 |
| | Mean crushing strength, lb/sq. in. | — | 3,875 | 5,085 |
| | Minimum crushing strength, lb/sq. in. | — | 3,300 | 3,970 |
| | Standard deviation | — | — | 621 |
| | Percentage below specified strength | — | Nil | Nil |
| F1 | Number of cubes tested | — | 20 | 26 |
| | Mean crushing strength, lb/sq. in. | — | 3,353 | 4,267 |
| | Minimum crushing strength, lb/sq. in. | — | 2,488 | 3,266 |
| | Standard deviation | — | — | 535 |
| | Percentage below specified strength | — | Nil | Nil |
| F2 | Number of cubes tested | — | 36 | 51 |
| | Mean crushing strength, lb/sq. in. | — | 3,271 | 4,847 |
| | Minimum crushing strength, lb/sq. in. | — | 2,305 | 3,060 |
| | Standard deviation | — | 713 | 823 |
| | Percentage below specified strength | — | Nil | Nil |
| F3 | Number of cubes tested | — | 5 | 19 |
| | Mean crushing strength, lb/sq. in. | — | 3,490 | 4,814 |
| | Minimum crushing strength, lb/sq. in. | — | 2,239 | 2,954 |
| | Standard deviation | — | — | — |
| | Percentage below specified strength | — | Nil | 5·3 |
| F4 | Number of cubes tested | — | 6 | 15 |
| | Mean crushing strength, lb/sq. in. | — | 2,584 | 3,651 |
| | Minimum crushing strength, lb/sq. in. | — | 2,052 | 3,078 |
| | Standard deviation | — | — | — |
| | Percentage below specified strength | — | Nil | Nil |
| B/W mix No. 4 | Number of cubes tested | — | — | 22 |
| | Mean crushing strength, lb/sq. in. | — | — | 4,342 |
| | Minimum crushing strength, lb/sq. in. | — | — | 3,203 |
| | Standard deviation | — | — | 431 |
| | Percentage below specified strength | — | — | Nil |

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The Paper, which was received on 27 May 1955, is accompanied by eleven photographs and twenty-three sheets of drawings, from some of which the half-tone page plates, folding Plates 1 and 2, and the Figures in the text have been prepared, and by five Appendices.

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## Discussion

**Professor A. L. L. Baker** (Professor of Concrete Technology, City and Guilds College) said that, as a former oil company engineer, he could appreciate the difficulties and experiences of the engineers and the contractors on that job. Oil companies always wanted a harbour and jetty constructed at such a speed that, if a tanker left another part of the world, the construction would be started and finished before it arrived! That desire for speed influenced the design very much.

He had not seen driving of rakers off the deck done before, but had often thought that it would be a very good idea, and he was pleased to see that it had been done.

He wondered if the contractors had considered tubes instead of hexagonal piles. He thought the tube was the ideal structural unit for a pile and now that tubes were becoming

more plentiful, particularly on an oil-company job, it might be worth while using tubes as piles instead of rolling two separate sheet-piles and welding them together to make one hexagonal section, but no doubt there were difficulties.

He was very pleased at the small standard deviation in the cube test results on the concrete. That was especially praiseworthy in the Middle East, and it appeared that the contractors' quality control and methods were well ahead of Codes of Practice in the United Kingdom. It was high time that Codes and Practice related standard deviation and the mean of the cube tests obtained, or which were anticipated, to the permissible stresses in design.

With regard to the jetty design, of special interest to him, he noticed that every precaution had been taken to protect those valuable tankers as much as possible. A breakwater had been built, in addition to a shock-absorbing jetty. In the usual manner, figures of kinetic energy absorbed had been given; those were interesting and valuable and confirmed that with fairly large vessels speeds of collision of 0·5 to 0·75 ft/sec could occur at not very exposed sites. That meant that quite frequently 1,000 in.-tons of shock absorption might be required to stop one of those tankers. The rubber fenders, which he thought were satisfactory in some ways appeared to provide the kinetic energy, but nothing had been said about the impact force. In Papers on jetties the kinetic energy was often quoted but not the ultimate impact. The figure for the ultimate impact was vital because the ultimate impact determined the number of raking piles required in the jetty to resist the maximum horizontal force, which was also taken of course by the tanker, a relatively very weak structure. He felt that engineers did not know enough about the strength of tankers, and he would like to see naval architects engage in a discussion at the Institution with engineers on the subject.

He found from Lloyds Shipping Registry that $I/Y$ was only 40 in.$^3$ for the average longitudinal frame of a tanker and that the frames were spaced at about 34 in. On a 30-ft span a 14-ton point-load acting centrally on one frame would produce yield in the steel. If the full 1,000 in.-tons shock absorption which the rubber fenders were capable of absorbing was used and Fig. 25 was followed, it could be deduced that an impact force was reached finally of 200 tons, so that if the full absorption value was to be used the tanker might receive a blow of almost 200 tons. That might be quite concentrated, because the fenders came to the vertical position only when they were pressed right back, and the tanker would very rarely lie exactly parallel to the jetty. It was therefore quite possible that the whole of the collision might be concentrated at one point.

That might be painting a rather pessimistic picture. Experience would show whether those fenders received very hard wear and occasionally dented a tanker's hull, and he would be very interested to know the results.

Fig. 34 showed a model of a recently developed gravity fender which was the basis of an alternative solution used at another berth where similar tankers were going to moor. The fender could recede about 5 ft and could move longitudinally 2 or 3 ft.

Fig. 35 showed the fenders as actually constructed. It could be seen that a blow which would cause an impact of 200 tons on a fairly rigid rubber fender would produce an impact of about one-third that value because the movement of the fender was about three times as much, and it would also be distributed over three fenders because the fenders automatically aligned themselves with the side of the tanker. Furthermore, they had a parallel travel instead of tending to take up a sloping position and so concentrating the pressure on one rib only in the tanker.

There was one other question regarding the figures of shock absorption. In some of the blows 40% of the kinetic energy was absorbed by the fender; that agreed fairly well with the proportion of the blow generally considered as taken up with a swinging blow when only one end of the tanker in a swinging motion hit the fender. In other cases, however, as much as 100% of the kinetic energy was taken up by the fender. Could the Authors add a little explanation on that point? He thought that those blows occurred either with the tanker pressing practically amidships or they must have been almost head-on blows against the fender.

Fig. 34

Fig. 35

**Mr A. H. Beckett** (a Chief Engineer of Sir Bruce White, Wolfe Barry and Partners) said the Paper was of particular interest to him because he knew the site well, having spent several months there for the other Consulting Engineers mentioned, Sir Bruce White, Wolfe Barry and Partners.

Under their direction he had taken charge of the hydrographic survey, and was puzzled by the alignment subsequently chosen for the breakwater. Accepting that speed of construction was essential and that weather protection had dictated the position of the roundhead, why had the costly construction in deep water been chosen instead of utilizing

the natural features and shallow water provided by Low Island and Pinnacle Rock? Why, in planning the areas for reclamation, had the large area behind the breakwater been chosen, involving more costly deep-water construction for the bundings?

Other disabilities of the selected plan were:—(*a*) that the area reclaimed was much smaller than it might have been, and (*b*) that the one zone in the harbour that would have offered the best possible protection from weather for shipping had been filled up with sand.

Particularly valuable was Table 1, which gave the investigations of berthing speeds and resulting shocks to the fender systems of the berths. Those results proved that the reduction factors, previously popular with so many designers, could not be justified, and that a jetty of that type should be designed to withstand the total kinetic energy of the berthing vessel.

What values had been assumed in the design for speed of approach and kinetic energy to be absorbed by the jetties built at Aden? Had an allowance been made for vessels berthing not truly parallel with the jetty face? The arrangement of resilient fenders appeared well capable of receiving vessels aligned with the jetties. There were special fender units at the ends which would operate only if a vessel was at an angle with the berth. If, however, a vessel did approach the needle jetty at such an angle, it would not be stopped by the fenders at all. Instead it would collide with the approach trestle.

The clean, bold, and ingenious design of the jetties illustrated how the great bugbear of construction work between high and low water could be avoided. The extensive use of mild steel for jetty construction in an atmosphere where steel corroded quickly indicated an implicit reliance on cathodic protection, but how could that be effective above water level? Would the Authors say what was the expected useful life of the jetties before serious rusting took place?

**Mr D. R. W. Watts** (Director, George Wimpey and Co., Ltd) said that, as a representative of the contractors, he wished to endorse and emphasize the Authors' point on the intense co-operation achieved on the job between the engineers of the owners, the Consulting Engineers, and the contractors.

In July 1952, before a contract was placed, the site was visited by the Authors, together with representatives of the contractors, and the broad outline of the design to be adopted was indicated by Mr Palmer to the contractors. The physical difficulties of the site and the type of rock to be expected after blasting had been assessed, and the design had been amended at that stage to allow the use of the maximum quantity of rock that would be attained. Also, at that time the type and location of access roads was fixed, since even the heaviest constructional plant had to be offloaded at Aden and taken ashore to a quay where no suitable crane was available and then carted over a hastily constructed desert road to Little Aden. It had also been appreciated that the quantity of large rock for the armouring that could be quarried in the initial stages would not be sufficient to keep pace with placing the core. An agreement had been reached on the amount by which the core would be allowed to lead the armouring, and the risks involved had been put to the owners by the Consulting Engineers and approved. The decisions at that stage had saved many weeks of construction time.

There was another point worth emphasizing. It was the chartering of the troopship *Dorsetshire*, which had taken the pioneer party from the United Kingdom to Aden and had been anchored there as a floating hostel for about 400 men for the first few months and used also as a temporary office and stores base, thus allowing the permanent construction to start at the same time as the temporary works.

Again, in the design of the jetties, the contractors had given to the Consultants the date by which the structural members would have to be ordered to allow them to catch the available rollings in the mills. With that date always in mind, various schemes had been discussed, and finally the scheme which allowed the speediest erection, together with satisfaction to the Consulting Engineers from the engineering point of view, had been adopted.

**Mr P. A. Scott** (Partner, Sir William Halcrow and Partners, Consulting Engineers) said that it was refreshing to read of a job of such magnitude which had finished not only before time but also below target cost. On p. 375 the Authors had drawn attention to the type of contract that gave rise to those happy results. The Authors did not say "gave rise" but he suggested that that type of contract had given rise to them, because recent experience of the more normal type of contract applied to a job of that size and distance from civilization had made him wonder if in many cases a target contract of that type was not in the long run more satisfactory both from the client's and the contractor's point of view. Where speed meant money to the client, it almost certainly was. But success depended upon the selection of a contractor who could produce and maintain an efficient organization, otherwise the final result was a costly and late job.

Apart from that aspect of the Paper, his chief interest was in the breakwater construction and the quarrying, and he proposed to confine his remarks to those two aspects. Time had obviously prevented use of a hydraulic model to test the section adopted for the breakwater, but would the Authors have used one had time permitted? An observed height wave of 10 to 12 ft was mentioned in the Paper, but for what height and period of waves was the breakwater actually designed? How had the wave heights been measured? That was well-nigh impossible to do accurately, and on two other harbours with which he was concerned two different types of wave-meter were being installed. Both of them were new developments; the one so far installed had had many teething troubles and that prevented a continuous record of waves. With the second one, the conditions precluded its installation for 2 or 3 months yet.

On the breakwater section adopted, Fig. 3, Plate 1, showed a change of slope on the seaward face occurring 1 ft below low water spring tides, whereas the more usual practice was to flatten the slope at a point below the lowest level at which wave action could be expected, say, a wave height below low water. Had there been any reason for that, apart from the obvious saving of rock? The Authors had drawn attention to the fact that the core was brought up to the rather unusual height of 2 ft above high water spring tide. Had that resulted in the loss of any considerable quantity of core material from wave action? He gathered that the breakwater was founded on a sand bottom. As a result, had any great settlement of the rock into the sand bottom been noticed? He noted that the concrete capping, according to Fig. 33, Plate 2, had been placed from 9 to 15 months after the core, which was not very long; he wondered if there had been any considerable settlement and cracking of the concrete core capping. Finally, on the breakwater, what relation existed between the measured profile of the breakwater and the net quarry excavation? Those were figures of particular importance in assessing any breakwater of that kind before it was actually built. Could the Authors give the number of man-hours per ton of rock?

Could the Authors add to the already interesting data on the quarry working given on p. 356 and in Appendix III? What was the height of face that was worked at the quarry and had it been necessary to remove much overburden? At what depth from the surface had the headings been driven? What had been the section excavated and the usual burden or distance from the face? How long had those headings taken to drive and load? Finally, assuming that the rock had been all transported by Euclids, how had the contractor managed to stockpile the armour stone, shown in Fig. 5, to the height at which it appeared to be stocked without a lot of double handling?

**Mr L. E. Nobel** (K. L. Kalis Sons, and Co., Ltd) said that, as a representative of the dredging contractors concerned, he had no questions to ask because he had been very intimately concerned with the work, but he would like to mention three points because they recurred on all jobs, at any rate where dredging was done. The first concerned organization. As the Authors had mentioned, the organization had worked very smoothly. The reason for the smoothness was twofold. First, a good organization was essential, but could not be worked without the right personalities and on that job those

personalities had been there. Then, as to the pure mechanics of organization, what had struck him on that job was that the executives had had time to discuss and to observe personally. That was not new, but its application had been rather striking with rather striking results.

The second point was that of tolerance. The tolerance on that job had been 1 ft, which a dredging contractor would normally consider very reasonable; yet the average dredging depth below that specified had been 18 in.—in other words, there had been 6 in. unpaid for. That was unsatisfactory to the contractor. Why had the dredging been carried beyond the tolerance? It was not because the tolerance had encouraged the dredging contractor to go deeper; it had been a question of sheer necessity. The soil conditions varied greatly from place to place, and it had been necessary to take into account that whilst in one place a certain depth would be sufficient, it might be insufficient in another place. It had been impossible to plan the whole operation from 50 yd to 50 yd to get that correct. In other words, there had been an inclination to make dredging deep enough in any case to avoid coming back. The result was that at some spots there were depths of 2 ft and even more than the specified depth and in other places only a few inches, with an average of 18 in.

He had often thought about what was a practical and fair tolerance. One method which to his knowledge had been applied was a tolerance which took into account the specifying of an average as well as a maximum. For instance, on the job at Aden, an absolute maximum of, say, 18 in, could have been specified, with an average of not more than 1 ft. That would have given the contractor a little more, but not all of his over-dredging. Another method to give approximately the same result and very simple to apply (it had also been worked before) was a tolerance which was paid for in any case. The specification stated that a certain minimum depth was to be attained, but the contractor would get paid for another foot and could do what he liked. On the job at Little Aden it would have given exactly the same result as the first method.

The third point was echo-sounding. The job had been the first where his firm had used echo-sounding for measurement for payment. The results had been reasonable enough, but during the job the echo-soundings sometimes gave queer results difficult to explain. One difficulty for the dredging contractors was that during the dredging the dredger-master had used a hand lead, because the dredger echo-sounders could not be provided. That had given a considerable difference from the results of the echo-soundings. Again that was a reason—reverting to the second point—why the depth had been so great in some cases. He did not know what the solution was, because echo-sounding had come to stay. Hand-lead soundings could not be used on jobs like Little Aden, but echo-sounding had to be handled with care and its applications should be studied further. It had recently come to his knowledge that the penetration of the supersonic waves depended on the frequency. Two types were available of 30 kc and 15 kc. It appeared that at 15 kc the wave penetrated deeper into the soil, particularly light soils, and therefore gave different results from the 30-kc set. That might be a pointer to the way in which an echo-sounding apparatus might be chosen for a particular type of soil.

**Mr K. A. Spencer** (Spencer & Partners, Consulting Engineers) observed that ships could be dry-docked for painting, but steel jetty piles could not. That point seemed to have occurred strongly to Mr Beckett who had rather taken the owners to task for using steel piles. However, for an oil-company jetty timber could not be adopted and whilst reinforced concrete could be used, the reinforcement was susceptible to corrosion and was more difficult to protect cathodically. Formerly the bugbear of civil engineers designing steel jetties had been the inability to maintain the piles below low-water level, but that could now be achieved by cathodic protection. Obviously the amount of current required to protect a structure was a direct function of the amount of bare steel, so it was advantageous for it to be coated.

The cathodic protection of jetties Nos 1 and 2 at Aden Oil Harbour was effected by a 150-A transformer-rectifier located on either side of each of the two approach sections.

The negative return cables were connected to the jetties and the positive leads fed graphite-anode ground-beds in hydrofill behind the sea wall. The system had worked very well for both jetties and dolphins. Initial design for No. 3 and No. 4 berth jetty called for four 150-A transformer-rectifiers, but temporary electrical drainage during construction of the jetty gave full protection with the low figure of only 375 A, so the fourth unit was not used. The coating was very well carried out, but some deterioration had, however, taken place and the fourth transformer-rectifier was being installed.

For marine structures hot-applied bitumen enamels were infinitely superior to cold-applied bitumen paint, and provided that civil engineering considerations allowed, the coating should extend to the toe of the piles. Experience with completely coated piles drawn at both Kuwait and Aden had shown that surprisingly little coating was removed below ground level. If coating was left off, say, the bottom 10 ft of the piles, there was a wastage of electrical current.

With reference to corrosion above low-water level it was shown on the Mina al-Ahmadi Jetty at Kuwait that appreciable protection had been achieved by cathodic protection to 6 or 7 ft above low-water mark, which had exceeded expectations.[1] In any event, steel structures could be maintained above low-water level by painting, whilst cathodic protection was effective for the submerged parts.

**Mr C. W. N. McGowan** (Head of Civil Engineering Division, Kuwait Oil Co.) said that he would like to ask a few questions. First with reference to p. 352 which dealt with the type of sea bottom encountered at the site, had the sea bottom been found similar in most respects to the sea bottom revealed at Mina al-Ahmadi in the Persian Gulf during the planning stage of the latter harbour? That sea bottom had already been described in an Institution Paper.[2] Secondly, to what extent had the bottom at Aden been prepared to receive the dumped material in view of the fact that the sea-bed was composed largely of hard shelly material? He would like to know what steps had been taken to prevent any tendency to side-slipping occurring.

On p. 352 it was also stated that it was very unfortunate that at the Port of Aden, including Little Aden, full records of wind had not been kept. It would be of immense value to consultants and port authorities if an invitation, perhaps emanating from the Sea Action Committee of the Institution, could be issued on a world-wide basis, to commence such records immediately for regular future maintenance, and also to collect together complete information on port characteristics, such as changes in the weather conditions throughout the year, rise and fall of tides, periods of heavy seas, marine growth, an analysis of the sea water, the temperature range throughout the year and other data in the form possibly of a global ready-reference manual for consultants and others.

Mr Scott had also referred to the wave height of 10 to 12 ft. That appeared rather greater perhaps than at Mina. There the length of the wave had been measured to be approximately 150 ft; he did not know what the length of the wave was at Aden.

On p. 353 he noticed that the main aim of the consultants had been to cater for the easy and safe handling of giant tankers. That statement had been endorsed by Mr Palmer in his opening remarks. Yet, according to p. 355, the dredged depth had been taken down to no more than 40 ft below chart datum, which he supposed meant 40 ft below low water. He could put the point in the form of a question or as a matter of interest; if taken as a matter for noting, then he would say that at Mina a tanker, the S.S. *Sinclair Petrolore* (which he believed was the largest oil tanker in the world) had called in November 1955 and taken away no less than 51,000 tons of crude oil, and with that load her mean draught had been 40 ft 9 in. She had been to Mina again and taken a second load giving a draught of 40 ft 11 in. So it seemed, therefore, that the Port of Aden would

[1] C. W. N. McGowan, R. C. Harvey, and J. W. Lowdon, "Oil Loading and Cargo Handling Facilities at Mina al-Ahmadi, Persian Gulf." Proc. Instn Civ. Engrs, Pt II, vol. 1, p. 249 (June 1952).

[2] See p. 252 of reference 1.

not accommodate a tanker of such size. It might be the policy of the oil company concerned; he did not know, and perhaps the Authors could give some enlightenment on the point. At Mina the depth to which the oil pier had been constructed was 50 ft at low water, about 10 ft more than the dredged depth at Aden. The length of the ship to which he had referred was 765 ft and the beam 106 ft. He believed that in Japan two tankers were to be constructed of no less than 84,000 deadweight tons with a length of 815 ft and a beam of 125 ft. (*Queen Elizabeth* and *Queen Mary* had a beam of 118 ft.)

On p. 358 it was stated that the roundhead concrete thickness was 6 ft. What steps had been taken by the consultants to prevent undermining by the sea of that large mass? He noted on p. 359 that the piles had been sand-blasted and coated with three coats of Wailes Dove No. 50. Mr Spencer had remarked that he did not care for the cold-applied coating, but would prefer the hot-applied coating. Hot coal-tar enamel had been used at the Mina pier, but as a result of extended trials with a considerable number of paint coatings, No. 50 had been replaced by another type of coating; at the moment it was chlorinated rubber. Whether the use of that type of paint was going to be continued for all time he did not know. Very shortly there would possibly be another series of extended trials to see whether there were other more suitable coatings now on the market. The first set of trials were commenced in 1951 and completed in 1953, and, of course, since their commencement about 4 or 5 years had elapsed, and the development of coatings in the paint industry today was rapid.

What was the estimated life of the rubber blocks, especially in the severe climatic conditions at Aden? Had the Authors considered the use of retarders in the concrete to prevent the very rapid setting times mentioned in the Paper? Had they felt that in the making of the concrete at Aden it had been preferable to avoid the use of retarders?

**Mr J. H. Jellett** (Docks Engineer, Southampton Docks, British Transport Commission) supported Professor Baker's suggestion that the subject of berthing impacts should be discussed between the Institution and naval architects. He had himself previously made that suggestion. Lloyd's underwriters should take part in the discussion, because they had a distinct interest, not so much in the case under consideration, where the same authority owned both the dock and a substantial proportion of the ships that berthed in it and where the expense of providing a resilient fendering was more easily justified, but with the ordinary commercial port where ships belonging to other owners sustained the damage and where the reason for anything more than the normal type of protection was not always obvious to those who had to pay for it.

He noticed that it was stated that the fendering was designed to take the normal berthing impacts, and he assumed that the figures in Table 1 were to be regarded as those normal berthing impacts. The problem, however, that the maintenance engineer had to consider was the abnormal berthing impact which always would take place.

How had the breakwater armouring behaved in practice? The maximum size of blocks specified was 11 tons, although an occasional 20-ton block was allowed. In many situations that would be regarded as a very light block for a breakwater armouring.

He had had a transient responsibility for the port of Newhaven, and had found that during the years protection of the breakwater had been carried out by 10-ton blocks. There had been no particular scientific reason for the 10-ton blocks except that was the maximum capacity of the only available crane for loading them on to the vessel used for dumping them. Feeling that those blocks were not performing any useful service, he had had a survey made, and some of the blocks had been found carried as much as 500 ft from the toe of the breakwater, which indicated that the protection they afforded against seas in the English Channel was not very great. He would therefore be interested to know whether any drawdown of the seaward slopes of the breakwater or the rubble mounds had been experienced.

In the Paper reference was made to arrangements to allow a crane to come along the top of the breakwater for maintenance, but he would be interested to know what permanent maintenance organization and plant was available.

Had any consideration been given to examining the welding by ultrasonic methods? At Southampton an all-welded structure had recently been completed which, although nominally designated a shed, had main first-floor beams about 125 ft long and 6 ft deep, all-welded, with one main joint butt-welded at the middle, so that the importance of securing an absolutely flawless weld in those joints particularly needed no emphasis. All those welds had been examined on site with ultrasonic equipment and one or two doubtful ones had been further examined by X-ray. On every occasion ultrasonic equipment was found to be, if anything, a bit pessimistic about the condition of the weld than in fact the weld justified. They had followed the practice, mentioned by the Authors in the Paper, of ensuring that all site welding was downhand, and special manipulators had been made to rotate the girders on the site so that both flange and web joints could be welded in the downhand position. He was sure that explained the very high standard of welding secured throughout the job.

He would like very much to see the more general adoption of a pile-set 48 hours after the pile had been driven. That would undoubtedly lead to considerable economies and the avoidance of unnecessary lengthening of piles which, once they had been given the chance to settle down, were adequate for the loads they were designed to support. One of the Authors would remember a case in which a number of piles which had failed to take their set had been lengthened and then, when the extensions had suitably matured and the pile frames had been brought back, not one of them could be persuaded to start again. So the expensive extensions had then had to be equally expensively cut off!

He wished he could look forward to a greater use of the system of placing contracts—a system in which the contractor could be selected before the design had proceeded very far. There was no doubt that that would lead to considerable economies in construction when the design could be matched to the particular capabilities and layout of the contractors' arrangements. It was not likely to become widespread whilst so many employing authorities in the United Kingdom attached what he could only describe as an odour of sanctity to the lowest tender secured by competitive tendering.

Finally, on p. 355, the turning circle had been given as 1,600 ft. The nominal turning circle in the upper swinging ground at Southampton was 1,400 ft and *Queen Elizabeth* had been turned in it at midnight.

**Mr E. Loewy** (Senior Engineer, Sir William Halcrow & Partners, Consulting Engineers) said that the importance of wave data certainly could not be over-emphasized. He would like to enquire apart from questions about wave height, whether data concerning lengths and direction had been available, or what had been done in the absence of them. In the last resort, would it not have been possible to carry out—if the decisions had been made early enough—some kind of model experiments not merely on the breakwater cross-sections but on the alignment of the breakwater as well? Breakwater cross-section models usually did not take long to make; valuable time was often lost in getting approval for their construction. Much valuable information could be obtained in about 3 months; he thought that, if those decisions could have been made in time, progress of the contract work need not have been held up and further economies might have been possible.

The cross-section of the main breakwater in Plate 1 showed the armour stone increasing in thickness to approximately 20 ft at the portion where there was a kind of beaching of the core. He thought that an excessive thickness for material that was always difficult to get and to place, and believed that model experiments might have shown possible economies there. Perhaps the answer might be that it was desired to place the core purely by tipping and the side slope of the core was consequently its natural slope. Might it not have been cheaper and quicker to flatten that slope and thus reduce the volume of armour stone? Could the Authors state the average density of the stone? Could the Authors also explain whether, in checking the breakwater slopes, they had always been able to carry out surveying from the crane boom whenever they needed to do so? Had there been a fairly constant swell, as might have been the case, it must have been

extraordinarily difficult to do even though the crane boom was available. Similarly, how had it been possible to ensure that the 12-in. thickness of blanket really was there as so neatly drawn on the cross-sections? Why had the hexagonal piles been filled with concrete, and had that been to protect them or to increase their load-bearing capacity? It must have been expensive and taken quite a long time.

With regard to construction of steel jetties by the widespread use of welding, had that widespread use been instituted for speed or to obtain structural continuity? He thought that a certain amount of high-strength bolting would have been permissible or even to be encouraged from the point of view of speed.

With regard to the form of contract, he congratulated the Authors and all concerned that they had been able to do the job at less than the revised target value. Would it be possible to find out whether any system of costing had been instituted so that a check was available throughout the course of the work upon the economy of construction? That was a bone of contention whenever such a contract arose. He was given to understand that in manufacturing industry no firm of any standing could hope to proceed with profit unless costing was instituted all the time. The extent to which such systems could be applied to civil engineering always seemed debatable; yet it was just in target contracts of that kind that such systems would have their greatest merit.

*** **Mr W. J. H. Rennie** (Director, Charles Brand & Son, Ltd) observed that the Paper would have been more valuable if methods of construction had been more fully described; he thought that on works of such magnitude and complexity a member of the contractors' staff might have been associated with the Authors in the preparation of the Paper.

The complete absence of cost was very disappointing; whilst it seemed reasonable to spend £1½ million on 6,000,000 cu. yd of reclamation and dredging, it was more difficult to understand the expenditure of a further £6½ million on the four tanker berths, the rubble mounds, and the breakwater. Would a sub-division of cost for the latter items help to clarify the figures given during the discussion?

The siting of the quarries at the root of the breakwater was very fortunate and no doubt the short haul influenced the adoption of Euclid wagons in construction of the breakwater and rubble mounds. Could the Authors give some further details of the quarrying, such as the type of explosive used, the methods employed for drilling and firing, and the size of the labour force? Their views on the efficiency of the heading blast system of quarrying would also be instructive. At Pulau Ubin, the island in the Johore Straits where Mr Rennie's former firm, Topham, Jones and Railton Ltd, quarried the granite rubble for the Johore Causeway, the more conventional methods of working a face in 20 to 25-ft benchings were adopted—the average monthly output from that quarry amounted to 52,000 tons. That compared fairly closely with the average output of the seven quarries at Aden; 42% gelignite was found to give the best results and the average ratio of stone produced to explosives used was higher than the best obtained on any one of the heading blasts recorded in the Paper.

Mr Rennie could not agree with the Authors' statement on p. 357, that "in the past breakwaters have been constructed largely by tipping all material, including the core, from rock trays". He believed that the most efficient and satisfactory method of placing rubble, and the one more usually favoured, was with floating craft using hopper barges for the underwater work; segregation was then minimized and the natural slopes more readily maintained. Could the Authors provide cross-sections showing the actual profiles of the breakwater and as tipped to show how closely the slopes formed by direct tipping from the Euclid wagons conformed to the theoretical sections? How did the actual quantities agree with the theoretical measurement?

**Mr Leslie Turner** (Principal, Leslie Turner & Partners, Consulting Engineers)

*** This and the following contribution were submitted in writing upon the closure of the oral discussion.—Sec.

mentioned that in connexion with the design of the welded jetties, he could bear testimony to the hectic speed with which the design had had to be produced and which had gone on for many months.

Owing to the nature of some of the intersections it had been necessary to construct full-size "mock-ups" in the office, to ensure that welders could gain access in order to carry out their work effectively.

During progress of the design the inevitable modifications had had to be made, owing to the availability or otherwise of the various sections. They were accommodated without delaying the work through the close collaboration of all interested parties. In general, the design followed modern standards adapted to suit site conditions, particularly rapid erection on the site. It would have been noted that the steel had come from different sources, some from the United Kingdom and some from the Continent, and it reflected great credit on the organization of the whole team, the consulting engineers, and the contractors, that the steelwork had fitted together smoothly and without trouble. At the same time it was a tribute to the Resident Engineer and his staff for any improvizations and resource on site in order to maintain and even improve on the tight programme for the whole enterprise.

The successful conclusion of the project in advance of schedule was significant proof that British engineering was on its toes and was ready to tackle work under the most onerous conditions of time and place.

**The Authors,** in reply, were pleased that Professor Baker had referred to the speed of construction, and also to the system used for driving the raking piles from the deck structure of the jetties; they were also glad to receive his commendation of the concrete quality control, since he was an acknowledged expert in that field. The alternative of using tubular piles had indeed been carefully examined during the design stage, but the advantages of the hexagonal piles were twofold; in the first place the hexagonal section provided a better moment of inertia in one direction than the circular section, and secondly, it had been decided that handling and fixing of the temporary bracing would be appreciably simpler with the flat surfaces of the hexagonal piles. Professor Baker was also an acknowledged expert on fendering, and his remarks on that subject were very instructive. The jetties at Aden had been designed to take, without serious overstressing, an ultimate thrust of 1,000 tons at any group of fenders at either end of any one of the four tanker berths, and Professor Baker's calculations for an individual fender confirmed that. Up to the date of the meeting there had been more than 400 berthings in the oil harbour, and apparently only one case of rather minor damage had been recorded. No damage had been caused to any of the ships during that period. The Authors were interested in the figures showing the new design of gravity fender; "Baker type" gravity fenders had been in use for 8 years at the Kuwait oil jetty and had received more than 10,000 berthings; one difficulty experienced at Kuwait had been that the comparatively long travel of the gravity fender required the supporting brackets to project many feet out from the jetty edge, and in a few cases those supporting brackets had been badly damaged. With regard to Professor Baker's question about kinetic energy, the Authors believed that fenders should be designed to take, on occasions, the full kinetic energy of a berthing vessel. They agreed with his comment that there was a variation from 40 to 100% in the absorption of the theoretical blow according to the Table of figures given for the actual energy absorption of the fenders. There were, however, a number of uncertain factors that should be taken into consideration when examining those percentages. The ship had almost certainly been either accelerating or slowing, it had probably been swinging, and a tug had been pushing or pulling on either side; it was scarcely possible to bring all those factors down to a mathematical basis. The Table of results given should therefore be regarded as an indication only of the magnitude of the blow that might be expected. An interesting point was that the maximum possible movement of the fenders was 15 in. and during the whole period of the records the maximum movement recorded was 13 in. That showed that the blow allowed for in the design was

certainly of the right order. The tests had now been discontinued, since the amount of work in recording every berthing accurately was considerable.

The fender groups were spaced at 165-ft centres, so if the tanker hit fair and square the point of impact would not be far enough removed from the centre of gravity of the tanker for the blow to be very much reduced.

The Authors thanked Mr Beckett for the valuable results obtained from the hydrographic and borings survey which had been carried out under his supervision. With regard to the alignment of the main breakwater, that had been very carefully studied, and a number of alternative alignments had been drawn out and considered, including an alignment picking up Low Island and Pinnacle Rock. It had been decided, however, that a breakwater on that alignment would have left the turning circle rather too much open to the south-east and the breakwater had therefore been moved farther north and aligned in a north-easterly direction to give better protection from the monsoon. The area of ground between berths Nos 1 and 2 and the breakwater had been reclaimed in order to provide space for road access and jetty buildings and also for the large number of oil pipes leading to those jetties. The general shape of the reclaimed area had been fixed partly by the presence of rock, which limited the outline of the area dredged to — 40, and partly in order to avoid an excessively long pumping distance for the reclaimed material. The Authors agreed with Mr Beckett that the full kinetic energy of a berthing tanker would have to be absorbed by the fenders on occasions, and the usual velocity assumed in berthing calculations was 1 ft/sec. Vessels berthing not truly parallel with the jetty face were catered for by the two fender piles sited at an angle at the outer end of each fender group, and they had received the first impact from tankers on a number of occasions. So far, however, no tanker had come within striking distance of the approach trestle. The steel structure of the jetty would certainly require careful maintenance in the humid atmosphere of Aden and, as suggested by Mr Beckett, the steelwork below low water was dependent on cathodic protection. The steelwork above water level was accessible for normal maintenance and, provided that was properly attended to, the Authors believed that the life of the jetties would be anything from 50 to 100 years.

Mr Watts had well brought into the picture the considerable amount of temporary work which had been necessary to enable construction to start. That important aspect was perhaps not sufficiently brought out in the Paper. There was certainly a great deal more involved in starting work on a bare peninsula, 25 miles from the nearest habitable town or place where plant could be unloaded, in providing the necessary access road through blowing sand, and in arranging accommodation, than there was when starting a similar work in the United Kingdom. The contractors deserved warm praise for their excellent planning and organization.

Mr Scott had pointed out the advantages of the target cost form of contract and there was no doubt that for the Aden job it was the only form of contract which permitted an immediate start with the work. The difficulty was to fix the target price at a figure which would provide a real incentive to the contractor. If the target price was fixed at too low a figure, the contractor might perhaps lose his incentive as the work neared completion. Under normal circumstances the Authors preferred the more usual schedule-of-rates contract, although they agreed that in many cases, particularly for works abroad, the most satisfactory contract was one tailor-made to fit the needs of the employer, the plant, and capabilities of the contractor. The acceptance of the lowest tender did not always, in present-day conditions, provide the most satisfactory results.

The breakwater had perforce been designed without prior model tests; had there been plenty of time to spare, such tests would, no doubt, have been asked for.

Various possible methods of measuring wave heights had been considered, particularly with the object of an early commencement of wave readings. All mechanical methods had been abandoned and the contractor's first job had been to construct a small dolphin just outside the site proposed for the roundhead. On it had been mounted a board with black and white bands 12 in. wide so that in all weathers fairly accurate wave heights could be read with a good pair of field glasses from the adjoining cliff top. The break-

water design had been based on an assumed maximum wave height of 14 ft, which was 2 ft above the maximum storm wave in Tawayih Bay, observed during the storm of July 1951, which had caused appreciable damage to the Admiralty breakwater at Steamer Point on the Aden side of the Bay. The change of slope was at mean low water springs, since that provided a "strong point" at the level where heavy wave action might, on occasions, be expected and also, as pointed out by Mr Scott, reduced the total volume of stone.

No appreciable quantity of rubble had been lost from the core in rough weather. On one or two occasions there had been a shaking-down and flattening-out of the core but on each occasion it had been made good by about half a day's tipping. No appreciable settlement of the core into the sea bottom had been experienced. It had been checked first by the quantities and secondly, by observing the sand levels on either side of the breakwater; had there been appreciable settlement the level of the sand would probably have been raised on either side and that had proved not to be the case. The Authors agreed that the concrete capping had been put on the breakwater very quickly after the tipping had been completed and some settlement was expected. It was for that reason that the concrete had been divided into 16-ft lengths with ½-in. joints between. The most recent report from the site indicated that there had been no uneven settlement, but since no concrete levels had been taken recently, it was possible that the whole breakwater had gone down evenly.

Net quarry excavations had not been measured, since the contractors had made a number of blasts in so many places that an accurate measurement in situ would have been a major operation. The voids in the armour as placed were of course considerable; it was thought that they might be about 50% and those in the core about 40%, though a large proportion of them had been filled later with sand during the process of reclamation.

The output of stone per man per month varied considerably with the output of the quarry, reaching a maximum of 550 tons in the autumn of 1953 when production had been greatest. It had later fallen to 220 tons when output had been less and a larger percentage of big stone had been required.

The quarry faces had varied considerably but the object had been to keep them about 30 ft high. Quarry "C" had been worked on two levels with that object. The quantity of overburden had been negligible. Prior to driving each heading a survey had been made by the contractor to plan the tunnels and position the charges; the plan of the headings had varied considerably, a T-head with two or three chambers being the most common. The section of the tunnel had been the minimum in which the men could work and was about 4 ft 6 in. high by 3 ft 6 in. wide. The hot and humid conditions had not assisted rapid driving and a little more than 6 ft in two shifts had been an average daily advance. The armour stone shown in Fig. 5 (facing p. 354) was some of the 8–11 ton armour for placing round the roundhead and had been stockpiled in view of the difficulty of obtaining all the large blocks at one time. Normally the stone blocks had been unloaded by the Lima 2400 directly into position in the breakwater.

Mr Nobel had raised the important but perhaps rather controversial question of the tolerance to be allowed in a dredging contract. If the rate in the Bill of Quantities was to represent truly the cost of dredging and was therefore to be applicable to either increased or decreased quantities without disadvantage to either party, the amount of tolerance allowed should be sufficient to enable a good dredging contractor to clean up to the minimum depth without dredging appreciably deeper than the tolerance line. The matter was complicated by the question of spillage while dredging the adjoining cut and during the period of contract, but to achieve the desired result the tolerance would vary with the material to be dredged. In the case of loose sand such as had been encountered generally at Aden, the tolerance necessary to achieve the above object had been shown to be greater than that allowed, and in another similar contract it might possibly be increased above the usual 12 in. With regard to Mr Nobel's remarks on echo-sounding, the area had been sounded every month in order to produce the monthly measurement. The echo-sounder had been, on those occasions, working over areas where there was often

an appreciable depth of silt which had not yet fully settled, and it was at that stage that variations between different sounders, and more especially between the sounder and the lead, might be expected. It was not considered that there should be any appreciable difference in the readings taken after the silt had had time to settle and in any case the contract under discussion had provided for a check with a lead of specified type, which check had in fact been carried out.

Some valuable information on the cathodic protection system at Aden had been contributed by Mr Spencer (the Consulting Engineer responsible for the design of that part of the work). It was a pity that some deterioration had been recorded in the coating of the piles in the finger jetty, but presumably the additional transformer would prevent further trouble. Hot-applied enamel had been carefully considered, and the only reason it had not been adopted was that the cold could be more quickly applied and the jetty construction time shortened thereby. The Authors agreed that piles should be coated for their full length.

The vital question of the depth of water to be provided for large-size tankers had been ably discussed by Mr McGowan. The dredged depth in the oil harbour at Little Aden had been agreed after careful consideration by the Oil Company. It was perfectly true that about 50 ft of water existed at the large oil jetty of Mina-al-Ahmadi in Kuwait, but the position of the head of that T-head structure had been largely determined by the need to allow sufficient manœuvring space inside the head for tankers to come into the berths on the shoreward side of the long jetty head; that manœuvring space had resulted in the head being sited at a distance out from the shore where the depth of water was 50 ft. Had the Aden jetties been designed for 50 ft at low water, their cost would have been considerably increased, probably by at least 50%, and possibly by 100%, taking the usual rough and ready rule that the cost of a jetty increased in proportion to a figure between the square and the cube of the depth. The sea-bed at Aden was generally of soft material and only a small fraction of the 6,000,000 cu. yd dredged had proved to be too hard for pumping ashore. No attempt had been made, therefore, to prepare the sea bottom before placing the breakwater, since it had been considered that there was no appreciable danger of side-slipping. The 6-ft-thick concrete parapet along the top of the breakwater was well protected by a 5–8-ton layer, as well as by an 8–11-ton layer, of wave-breaker blocks on the outer face of the breakwater. The parapet had been constructed in short lengths to allow for some settlement in case some of the smaller material immediately under the concrete should be washed away.

The life of the rubber blocks used behind the fender piles could only be estimated, for the Authors knew of no case where similar blocks had been in use sufficiently long to require changing. The blocks were protected from the sun and their life would not be less than 10 years and might be considerably longer. The use of retarders in the concrete had been considered but it had been thought preferable to cool the water, and that cooling had achieved the desired result.

The Authors were in full agreement with Mr Jellett's observation that the problem of the abnormal berthing impact was the main concern to the maintenance engineer. A jetty structure, however, had to be designed to stand up to the *heaviest probable* loads, using normal working stresses. In addition, the Authors' practice was to give a reasonable reserve of strength in the main jetty structure to withstand reasonable overloads. It would be prohibitively costly to design a jetty to take the greatest load which could possibly be caused by a giant tanker coming bow foremost against the jetty at a speed of several knots; that would have to be treated as an accident. The whole problem of the design of fendering to protect structures against damage from ships, and also to prevent excessive damage to the ships, could with advantage be discussed between civil engineers and naval architects, and the Authors hoped that Mr Jellett would take the lead in fathering a joint Paper to the Maritime Division of the Institution. The wave-breaker blocks in the main breakwater had been designed in a somewhat similar manner to the jetties, namely to withstand forces rather larger than the maximum forces normally expected; as already stated they had been designed for 14-ft waves. No doubt 10-ton

blocks would not be sufficient protection against a strong south-westerly storm in the English Channel, as Mr Jellett had found in the case of Newhaven.

With regard to the future maintenance of the breakwater, one of the Manitowac cranes used on the erection of the refinery had been retained for that purpose, together with Euclid wagons for transporting the blocks. A small stock of stone had been left at the quarry, sufficient to deal with any minor settlement, and the quarries could easily be re-opened should larger quantities be required. On the inside of the slab on top of the breakwater the filling had been brought up to the same level, so as to provide a roadway for the crane and Euclid wagons.

The alternative of ultrasonic testing for the welding had been considered and the Authors agreed with Mr Jellett that ultrasonic tests would probably detect smaller flaws than those observed with gamma ray. The great advantage of the gamma, or X-ray, was the permanent record of the weld; the inspectors on the site saw the photographs and after that they were available in the office for all to see; the moral effect of that was considerable.

With regard to contract procedure, if a job of that size had to be designed and built in 2 years, the contractor should be given the word "go" at the same time as the design was started. An advantage of the more normal procedure, where the design was completed first, was that different contractors could use their experience and ingenuity to propose different methods of carrying out the work, and that often led to a substantial economy in the cost of construction.

Mr Loewy had commented on the design of the main breakwater, in particular the thickness of the layers of armouring stone, and also on the use of model tests. In the case of the Aden breakwater, the overriding criterion had been speed of construction and the core had therefore been brought up to a greater height than usual and tipped from Euclids, and the steep side-slope of the core had therefore fixed the inner edge of the armouring. The outer face of the armouring had been built above water to the steepest slope considered safe and that slope, as had already been pointed out, had been steepened below low water level. It was therefore very doubtful whether model tests could have led to any economies; in any case there had been no time to carry out any model tests. There had been no data at the site regarding size and direction of waves, but from a study of such storm-wind data as existed for that part of the world it had been concluded that the worst storms occurred in the south-west monsoon; one such storm was known to have produced waves estimated at 10–12 ft in height. It would certainly be helpful to engineers responsible for the design of harbours if records could be kept in all ports of the world, as suggested by Mr McGowan, of such important data as wave heights.

Mr Loewy had asked about the average relative density of the stone; it was 2·57.

Mr Loewy had also mentioned the importance of costing, but the difficulty in a civil engineering contract was to produce the results in time for any effective action to be taken. In the case of Aden, the Oil Company had placed considerable reliance on the good-sized team of engineers and inspectors, provided by the Consulting Engineers, to ensure that the work was economically carried out. It had been possible to carry out surveys of the breakwater from the crane boom more or less as required. A heavy lead had been used and no great trouble had been experienced from the normal swell.

With regard to the blanket of stone on the inside of the rubble mounds and breakwater, the procedure used had been to check the core slope before placing the blanket seal, for the inside slope of the core varied somewhat in plan, being over-thickness in places due to rapid tipping; in addition there were the turning places. The first layer of the seal had then contained extra material, owing to the irregularities in the core to be filled up before coming out to the angle of repose. The second layer had been very closely to the specified thickness. The hexagonal piles had been filled with concrete to protect them; once the operation had been organized it had not taken a great deal of time, forty-six jetty-head piles in berth No. 2 had been hearted in 2 days. The welding of the steel jetties had provided structural continuity; it had been quick; and had resulted in a smooth and clean surface for sand-blasting and painting.

Mr Rennie had asked about the efficacy of the heading blast system of quarrying; it had been found to be the best system to provide the quantities of large wave-breaker stones required and, except for the latter stages of the work all the small stone had also been needed. With regard to the method of construction of the breakwater, the Authors agreed that many breakwaters had been constructed by dumping from barges, although there were several months each year when that would have been a very difficult operation at Aden. The point the Authors had intended to make was that the introduction of tipping from Euclids introduced the disadvantage of some segregation. The breakwater section as built followed closely the theoretical section on the seaward side. On the inside, turning places and a certain amount of over-tipping for other reasons, had resulted in the quantity of core material being in excess of that in the Bill of Quantities. Although seven quarries were mentioned at Aden they had not all been operating at the same time. Various explosives had been tried in the early stages of the work but open cast gelignite had proved to be very satisfactory and had been mainly used in the later stages. The Paper unfortunately could not be extended in length to include a contribution from the contractors on their construction methods. The total cost of the project appeared high, but it should be remembered that present-day costs were probably three times their pre-war figure, and that the Aden contract had been carried out at considerable speed, demanding more plant and more staff than usual.

The Authors thanked Mr Turner for his interesting contribution and also for the considerable help given by his team of designers in working out the details of the welded joints; the full-size models of the various joints had been extremely useful.

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The closing date for Correspondence on the foregoing Paper was 15 May, 1956. No contribution received later than that date will be published in the Proceedings. —Sec.

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# FURTHER DISCUSSION ON

## Paper No. 6098

## "The raising and strengthening of the Steenbras Dam" by

**Solomon Simon Morris, B.Sc.(Eng.), M.I.C.E.**
**and William Scott Garrett, B.Sc., A.M.I.C.E.**

This Paper was presented for discussion at a Supplementary Meeting of the Institution on Thursday, 13 October, 1955, and at a meeting of the South African Institution of Civil Engineers, in Johannesburg, on Tuesday, 25 October, 1955.

The Paper and the London discussion were printed in the Proceedings, Part I, January 1956, p. 23. The Johannesburg discussion, the correspondence, and the Authors' consolidated reply are printed below.

## Discussion (in Johannesburg)

**Mr L. Buchler** appreciated the concise and instructive description of the work carried out, and the exposition of the practical difficulties encountered during the construction, which the Authors had succeeded in overcoming.

The method, entirely new in South Africa, which was adopted for the raising and strengthening of the Steenbras Dam, involved a very interesting departure from the middle-third criterion, which demanded that the resultant force should intersect the middle third of the wall section under any expected loading condition. Whereas, in the case of gravity strengthening prior to raising of an existing dam, the measure of thickening was determined by the considerations necessary to satisfy the above criterion, in the case of the method described by the Authors the total compression force required to counteract the increased loading of the raised dam was applied by the cables a few feet only from the upstream face. Since a gravity section was normally designed in such a way that the resultant force was just within the upstream side of the middle third when the reservoir was empty, for the same loading condition the application of an additional force transmitted by the cables near the upstream face would cause the resultant force to be in the upstream-side third of the section. The measure by which the resultant force would be outside the middle third depended on the position of the cables, on the ratio of the maximum flood level before and after the raising, and on the position of the horizontal section of wall under consideration relative to the top of the wall. For each horizontal wall section there was a critical water level in the reservoir at which the resultant force intersected the upstream third. Should the water fall below that level, the resultant force would be in the upstream third. Extreme conditions would be reached when the water dropped below the section which was considered, and the magnitude of the tension stresses might be such as to cause cracks on the downstream face of the dam. The cracks would probably close with raising the reservoir level, but would open again under converse conditions.

To obviate that undesirable tendency, an obvious, but not the easiest, way would be to move the point of application of the post-stressing forces so near the middle third of the section as to reduce the possible tension stresses to the point of being practically insignificant. That would involve angle drilling for the cable holes. In view of the difficulties experienced in the case of the Steenbras Dam in keeping the direction of the vertical holes within permissible tolerances, the Authors' views on the practical possibility of drilling angle holes would be appreciated. It was realized that moving the cables farther from the

upstream face would involve increasing the size of the cables, or the number of them, or possibly both.

Perhaps a more practical way to protect the lower part of the downstream face against cracking, if the magnitude of the tension stresses should warrant it, would be to provide a reinforced concrete lining anchored in the old concrete. That would, thought Mr Buchler, be particularly desirable on the spillway section where the concrete was exposed to the impact of the jet.

There could be little doubt that, within certain limiting conditions, strengthening of an existing dam by the method of prestressing might offer essential advantages when compared with the conventional gravity strengthening.

**Mr G. Whysall** referred to the Authors' suggestion that dams might be designed *de novo* on the principle adopted. Whilst that might be used in some cases Mr Whysall believed that it would play a far more important part in the raising of dams.

Most rivers in South Africa carried silt to some degree and in a lot of rivers where dams had to be built the silt load was heavy. So far no satisfactory method of combating that menace had been found and the only alternative was to resort to progressive raising to restore the capacity which had been lost by silting. In some dams designed by the Irrigation Department provision had been made in the original design for no less than three raisings to be followed by the installation of crest gates.

Raising a concrete dam in the conventional way entailed thickening the wall on the downstream side and apart from the difficulty of getting a good bond between the old and the new concrete and providing for shrinkage there was always the question of the foundations for the new work. Unless the rock was particularly sound a certain amount of excavation at the toe of the existing structure would have to be done. If that excavation was appreciable, there was the possibility of endangering the original structure so, where it was intended to raise a dam, the foundations for that extra work would have to be laid when the dam was built. The extra foundation served no useful purpose until the dam was raised and consequently represented capital lying idle. With the method described by the Authors the dam could be designed and built as a simple gravity structure in the initial stage and the prestressing added when the time came for raising.

In making provision for the subsequent raising of a dam by prestressing the question arose of whether the anchorage holes should be drilled when the dam was built and the necessary holes left in the wall. It would appear from the Paper that some difficulty had been experienced in drilling the holes through the wall to the necessary tolerances and it might have been simpler and cheaper to cast the holes in the concrete when the dam had been built. The drilling of the anchorage holes in the initial stage might, if the raising were not carried out for some years, lead to the weathering of the rock as the holes were bound to become filled with water. The weathering might weaken the anchoring of the cables unless the holes were reamed out. At first glance it would appear that the best procedure would be to cast the holes in the concrete wall but leave the drilling of the anchorage holes in the rock until the actual raising was to be undertaken.

Would the Authors give some additional information on the provision of the correct quantity of grout for holes which had been drilled too large? The length of grouted cable was only given in one case where the cable had failed at the prestressing load. That was 3 ft 4 in. instead of 8 ft. Since other cables had apparently failed at a smaller load it seemed reasonable to assume that the grouted length was even less and that the cross-sectional area of the holes was perhaps as much as three times what it should have been. It was felt that it would be dangerous simply to put in three times as much grout as would be required for a normal hole on the off-chance that it might be larger. If the hole happened to be the correct size the grout would rise to a height of 16 ft above the design level and too long a length of cable would be anchored. That could be serious in a shallow hole, for it would upset the relation between the extension of the cable and the prestress applied. It might also have an effect on the allowance to be made for creep. Could the Authors say how that problem had been solved?

The raising of dams was such an important matter in South Africa where very few dams

could be built without the prospect of their having to be raised at some later date; it was felt that the question of cost was an important one and it would be appreciated if the Authors could give some figures for the cost of drilling the holes and anchoring and prestressing the cables.

## Correspondence

**Professor R. G. Robertson** (Professor of Civil Engineering, University of Cape Town) observed that much interesting detail had had to be omitted from the Paper, e.g., the ingenious methods of plumbing the boreholes and the details of the viscometer and of the cable anchorage "brush".

He wished to make a correction to the cable extension graph Fig. 4b, which he had suggested making and for which he had taken the readings, which were not in inches but 1/10-in. units. The test had been started before an initial zero had been set, which accounted for the absence of readings below 30 tons, so that the change in slope in the graph at 30 tons was not thought to be a true representation. At higher loads the strains agreed exactly with those of Figs 4a and 4c, which showed that the curve at extreme load was due to yield of the wire and not of the anchorage. All three graphs indicated a value of $E = 23 \times 10^6$, whereas a test on a single wire gave a value of $E = 29 \times 10^6$ lb/sq. in. That difference in value was normally found for a twisted wire cable such as the one in question. It might be noted in Fig. 4 that the load shown was that in each limb of the looped cable and the actual applied load had been double that shown.

Could some of the prices be furnished, for the method of stabilizing the structure could be applied to other works? He had obtained quotations for similar work from the same firm in 1926, for stabilizing the tall masonry abutments of a 100-year-old 114-ft-span arch bridge at Bath (England) that had to be strengthened for modern traffic.

The method had not been approved in that instance and a simply supported relieving span, constructed over and between the old cast-iron arches by a system of prestressed concrete girders, was used. It was possible that his original method was the correct one but the Ministry of Transport at that time were not confident of its suitability.

In regard to the sealing of the bores to limit the inflow of water which was stated to have occurred at the bottom, possibly at the level of the anchorages, at a rate not exceeding $1\frac{1}{2}$ gal/hour, it appeared that that might have been a cause of defective anchorage, for the quantity of water mentioned could displace 5 ft of the anchorage grout, unless the bores were filled with water before the grout was introduced so that the pressures were equalized.

Similar trouble had occurred in Professor Robertson's experience with cast-in-situ piles of the type in which the casing was withdrawn as the concrete was deposited. The piles had been driven through a gravel fill, 30 ft deep, to a hard substratum and there had been a high water-table at the site, which had forced a flow of water through the concrete into the unfilled part of the casing, which had completely removed the cement content from a section of the pile near the foot.

**Mr A. H. Clark** (Senior Engineer, Sir William Halcrow & Partners, Consulting Engineers) said that a successful method of raising an existing gravity dam at relatively small cost, avoiding the complications and expense of adding weight to the back of an existing structure, must present attractive possibilities to water and water-power undertakings. An equally attractive prospect might be, in suitable cases, the deferring of the full cost of a project by building a dam to its partial height for completion later. In that event, cable holes for future use would doubtless be formed in the initial structure with considerably less difficulty and expense than would be involved in later drilling. Similarly, access to future anchorages to facilitate their construction might well be provided.

In the procedure described in the Paper, however, there seemed to be certain difficulties, inherent in the process, which have not been conclusively shown to have been overcome. One of them was the grouting-in of the cables. The Authors rightly stressed the importance of doing that successfully since, if assured protection against corrosion of the

steel cables was not attainable, the raised dam would have a limited life. They had referred to precautions taken to ensure that the cables were "entirely sealed in a waterproof cement medium" and quoted leakage of grout through the strands of the cable as "positive assurance that the final seal was completely watertight." It was presumably because of the small difference in size between hole and cable that the diameter of tube through which the final grouting was carried out was limited to ¼ in., which in turn precluded a water/cement ratio lower than 0·65.

With a grout of such consistency, a certain amount of settlement of cement particles would take place following completion of grouting and before initial set occurred, resulting in supernatant water at the top of the hole. Moreover, the grout during setting and hardening would be expected to undergo appreciable shrinkage, resulting in formation of cracks at intervals throughout the length of each cable. In either or both those circumstances, protection of cables appeared to be incomplete. It would be interesting to know whether the Authors considered any such risk was involved.

In regard to tensioning of the cables, the specification required cables to be tensioned initially to 77 tons load and to have a residual load of not less than 70 tons after 28 days. The Paper reported six failures of single cables during the carrying-out of the work as a result of failure of anchorages. The occurrences prompted the question whether other anchorages, although withstanding the initial load of 77 tons, might only just have done so and have been near failure. Although one test cable withstood safely an average load per leg of 95·4 tons (the ultimate strength of the leg being 110 tons) the remainder appeared to have a known factor of safety of only 1·1 which appeared low in view of the failures which did occur. Moreover, as stated, the failures were in single legs; it would be interesting to know whether that might have resulted from stressing of one leg of the pair more than the other, as a consequence of friction at the semicircular heads. A more elaborate head to ensure positive equalizing of force in the two cable legs might perhaps have been considered. Any reasons for not using such a head would be of interest.

One further query arose from the statement on p. 36 that the contractor was responsible for design. Since the form of contract including a detailed specification, extracts from which were quoted in the Paper, was presumably drawn up by the Cape Town City Engineer's Department under the direction of the Board of Engineers, the statement was not altogether clear. Perhaps the extent of the contractor's responsibility could be enlarged upon. Had any form of control over the design and construction of dams existed in South Africa, corresponding to the Reservoirs Act in the United Kingdom?

**Mr J. A. Banks** (Partner, Messrs Babtie, Shaw & Morton, Consulting Engineers, Glasgow) noted that all the cables were grouted and apparently no provision was made for subsequent observations to ascertain the loss of stress by relaxation. Although fully 20 years had elapsed since Coyne gave effect to his original conception at Cheurfas, the technique was still new and records of relaxation would be helpful for future designs. Furthermore, in the United Kingdom, an engineer making a statutory inspection of a post-tensioned dam under the Reservoirs (Safety Provisions) Act should, if possible, have some facility for checking the stress in the tendons.

The Authors mentioned evidence of joint leakage in the dam. Were any measurements taken of deflexion after prestressing, and was there any significant reduction in joint leakage as a result of lateral strain induced by prestressing?

Mr Buck had hoped to see some development leading to more specific determination of the required depth of anchorage and referred to the full-scale anchorage test in connexion with the Allt-na-Lairige Dam.[9] In that experiment the load of 4,400 tons was resisted partly by the weight of the rock above the anchorage, but mainly by the structural strength of the rock itself. The kinks in the plotted curves to which Mr Buck referred occurred during intervals of rest between increments of applied load and were attributable to adjustments in the rock structure. When the load was released, the rock recovered

[9] "Employment of Prestress Technique on Allt-na-Lairige Dam." Paper R.68. 5th Congr. on Large Dams, Paris, 1955.

to the extent of about 80% of the total deformation, indicating that about one-fifth of the movement was attributable to adjustment in fissures and that, apart from that, the rock behaved elastically. Up to a load in the range 1,200 to 1,400 tons no significant adjustment of the rock structure seemed to have occurred, but at that point, as indicated by the rather pronounced kink on the plotted curve, there was a marked increase in the rate of displacement of the rock and a continuing creep when the pressure was sustained without increment. It was deduced that at that load local failure of the rock occurred in the vicinity of the jacks; that was confirmed to some extent by analysis on the assumption that the rock was an elastic medium and that the jack pressure acted within a hypothetical geometric cavity.

The arrangement of the test pit and jacks was as shown in Fig. 14, and the cavity was assumed to be of the form indicated in Fig. 15. In an undisturbed rock mass there would be a vertical pressure $p_z$ in the plane $z$–$z$ arising from the weight of the overburden of rock.

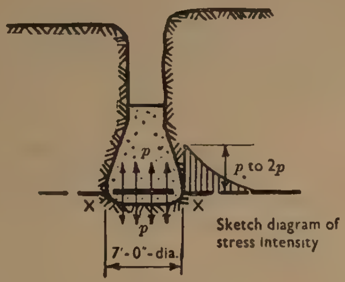


FIG. 14

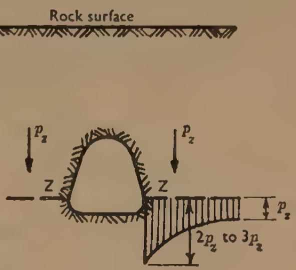


FIG. 15

Excavation of the rock to form the cavity would produce a concentration of the vertical compressive stresses at points $z$; Terzaghi and Richart[10] had given concentration factors for various geometric shapes of cavity. On the basis of those factors the compressive stress concentration at points $z$ on the periphery seemed to be about 2 to 3 times the value of $p_z$. By inversion, it might be assumed that the vertical pressure $p$ exerted by the jacks in the pit gave rise to tensile stresses in the rock at points $x$ in the range of 1 to 2 times the pressure $p$, the diagram of stress intensity being rather as shown in Fig. 14.

Laboratory tests on the homogeneous granite excavated from the test pit gave a crushing strength of 19,000 lb/sq. in. and a shear strength of 1,400 lb/sq. in. Assuming that the tensile strength of the granite was equal to the shear strength and adopting an average concentration factor of 1·5, the vertical pressure resulting from jacking in the cavity required to cause cracking at the periphery would be about 1,400/1·5, i.e., 930 lb/sq. in. That intensity of pressure acting over the plan area of the cavity, 7 ft dia., amounted to a total jacking load of 2,300 tons. The difference between that figure and the load of 1,200 to 1,400 tons at which cracking occurred in the test was a measure of the strength of the naturally fissured rock compared with homogeneous rock, indicating a ratio in that instance of about 0·6 to 1. It seemed, therefore, that Mr Buck's deduction from the theories of Malan and Mindlin that a load of 4,000 tons would just begin to open up a fissure assumed to be present in the rock was excessive.

Within practical limits, calculations related to the strength of homogeneous rock would give similar results irrespective of the depth of the anchorage and, therefore, did not provide a means of determining the anchorage depth. The Allt-na-Lairige test indicated that in the particular case there was a reserve of anchorage value beyond the load causing

[10] Karl Terzaghi and F. E. Richart, "Stress in rock about cavities." Géotechnique, vol. 3 (1952–53), p. 57.

cracking of the rock in the vicinity of the jacks and that that load could be regarded as the "yield point." Full-scale tests seemed, on present knowledge, to be the only effective means of determining the requisite depth of an anchorage and the character of the Allt-na-Lairige test, which was related to an anchor plate in an excavated pit, might have little application to a cable grouted in a borehole.

The Authors expressed the view that assessment of the depth of anchorage called for considerable experience and engineering judgement; that had certainly been confirmed at Allt-na-Lairige. Excavation for the foundation of the dam revealed that, whilst the rock was of similar character to that at the test anchorage, much of the joint structure and also some minor faults were filled with greenish-coloured clay which was not present at the test anchorage and could have had a lubricating effect facilitating movement of the rock under tension. Had the rock at the site of the dam been exactly similar to that found at the test anchorage, then an anchorage depth of about 18 ft would certainly have sufficed. However, in light of the circumstances, it was deemed advisable to increase the anchorage depth to about 26 ft and it was significant that that was practically in accord with Coyne's practice, allowing a weight of rock within a 45°-inverted cone equal to the uplift. Further data from full-scale tests on future works would probably lead to anchorages being established at a shallower depth than had been the practice hitherto; at the present stage of experience it was perhaps prudent to be conservative and the cost of a moderate increase in the depth of anchorage was small relative to the overall cost of the project.

**The Authors,** in reply, said that they were particularly interested to hear that Messrs Binnie, Deacon & Gourley contemplated raising a dam using a method similar to that described, by as much as 45 ft. Such work would lead to a significant extension of existing knowledge and could, for example, establish a valuable precedent if the future further raising of the Steenbras Dam were ever to be undertaken.

The Chairman (Mr Gourley) and Mr Walters had both compared the spillway capacity provided with that envisaged by the Floods Committee Report. That report had, *inter alia*, been taken into account in assessing the desirable capacity; greater weight, however, had been placed on the South African Irrigation Department's report (see reference 2, p. 48), not only because it was based on observations made locally, but also because the flood frequencies actually occurring at Steenbras over the operational period showed fairly good agreement with its findings.

The Authors agreed with Mr Walters that the difficulties they had referred to in the design of a siphon spillway could be overcome. As indicated in the Paper, however, those investigations would have taken some time and it was important to expedite work in order to avoid water restrictions. A further and even more important factor was the advantage that work undertaken for the Coyne method would still be of value in the event of a future major raising of the dam.

No provision had been made for observing in detail the behaviour of any of the cables at Steenbras after stressing and grouting, although the tension had of course been checked after one month and before final grouting-up.

In reply to Mr Roberts, the curved part of the original dam had been constructed as a gravity section and, when considered as an arch, had been found to be safe.

The Authors had not intended to give the impression that steel exposed to the Steenbras water did not show signs of corrosion. On the contrary; steel exposed in the dam was heavily corroded; but steel exposed in a hole drilled through the wall which had been pressure grouted with neat cement showed no corrosion; the residual alkalinity left in the hole by the cement was enough to neutralize the water.

There was no protective treatment of the water face since more than adequate cover was provided. A close inspection of the upstream face of the dam had been made prior to the inception of the scheme and it had been found that deleterious water action was observable only to the depth of approximately $\frac{1}{8}$ in. in the most affected areas, i.e., where the wall had been subjected to alternate wetting and drying and to wave action. All holes carrying cables had been pressure grouted to 200 lb/sq. in. with neat cement before the insertion of cables and after tensioning.

The concrete in which the majority of the total cable was encased had a cement content of about 420 lb/cu. yd.

The Authors did not altogether agree with Mr Harris that little development of the Coyne process had taken place during the past 20 years. The principle had of course remained the same but details of construction had changed considerably, particularly in the use of smaller boreholes and of smaller cables with more uniform distribution of load.

The curvature of the cable over the precast head did not induce any serious increase of stress. The ratio of jacking-head diameter to wire diameter was about 160, which was not unduly low. The conditions were analagous to those encountered with a thimble on a mine rope; and no difficulty had been found in regard to the cable taking up its position, nor had any failure or distress of the cables been visible during stressing by loads at least 10% in excess of the maximum working loads.

Bitumen sheathing had been adopted for the large-diameter cables originally used by Coyne, partly so as to permit observation of the cable loads after the initial stressing, but it had, in general, now been abandoned in favour of grout encasement. Cement grouting was more economical and was easier, since the difficulties of inserting fairly small-diameter cables into the small boreholes without damaging the bitumen protection was avoided. The protection afforded by cement grouting and concrete was now considered the best obtainable.

The jacking heads had been blocked up on precast concrete packings of thicknesses ranging from 8 in. to 2 in., capped by steel plates of $\frac{1}{2}$–$\frac{1}{4}$-in. thickness.

Mr Widdowson's report of work at Tansa Dam in India was very interesting. Rock conditions were possibly different to those found at Steenbras. Nonetheless, the results reported by Mr Widdowson reflected the greatest credit on all concerned.

Mr Addison had mentioned the principal measures taken between the first and second raising of the dam for development of the Steenbras scheme. A further measure had been the scraping of the cement-lined second pipeline, some details of which had been given by Mr G. H. Lunt in *Chartered Civil Engineer* (March 1950). Another measure had been certain minor modifications to the filtration plant which enabled the design output to be considerably exceeded in practice.

In reply to Mr Barlow, the capacity of the dam was now 7,500 million gallons. No detailed proposals had been prepared for a future major raising of Steenbras Dam; that would have to be undertaken together with the diversion of additional flow from adjoining areas into the catchment.

No cracking had occurred at the junction of the straight and curved sections of the dam and there had been no visible changes in the number, disposition, and extent of the minor cracks and joint openings observed before the work commenced. There had, however, been a visible decrease in the seepage through horizontal construction joints, particularly on the spillway section.

The difference in uplift assumption to which Mr Barlow had drawn attention was simply the small difference between the Departmental figure and the value adopted in Coyne's design. It was fallacious to assume that uplift was much less than those assumptions because boreholes were substantially watertight; uplift could be developed in microscopic pores and fissures which would be classed as watertight in terms of the standards referred to in the Paper.

Even with no uplift, however, the spillway section would not have been stable with a flood of the amount for which provision had been made.

Compressive stresses transmitted from the arch section of the dam to the straight section, had been taken into account only for the raised work. The magnitude of the stresses involved was not great.

The organization of local government service in South Africa differed somewhat from that in England. In South Africa a City Engineer had under his control activities which in Great Britain, in the larger towns at least, would normally be functions of separate departments. Among them was not only the Water Undertaking, but also Public Cleansing, Architecture, Building Regulation, Town Planning, Forests, Parks and Gardens,

Amenities, and Control of Stores. The personal experience of one of the Authors indicated clearly the necessity for co-ordination of all those diverse activities; and the South African procedure of centralizing work under a City Engineer had the considerable merit of avoiding the danger—now apparent even in Great Britain—of having engineering organizations subordinated to a lay administrator. If engineers were not prepared to take responsibility for "water, sewerage, highways, and town planning" then it might be regarded as expedient—and it certainly would always be possible to find a lawyer, an accountant, or a clerk who would not be so diffident!

Civic administrators throughout the world were all agreed that the centralized direction of all engineering activities under an engineer led not only to greater efficiency and economy, but to better exploitation of municipal resources.

The waterworks branch of the City Engineer's Department of Cape Town was of course a specialized operational force with a fairly large complement of civil engineers properly qualified, not only in their profession but also in their particular speciality.

Although the drilling tolerances achieved should, in general, ensure that cables did not touch the side of their holes, particularly in the rock foundation, it was possible that—as referred to by Mr Buck—some cables did touch the sides of the holes. Since all holes had been pressure grouted there would be no reason to fear corrosion on that account. The only significant effect might be a certain amount of friction produced at areas of contact.

A device to measure the top level of the grout had in fact been devised after the first anchorage failure but had not been completed in time to be used. The use of that device had not, however, been necessary; the simple procedure adopted had proved fully successful.

The load on the cable had been measured solely on the jacks and not on extension, since the elongation of a cable was affected considerably by the wires bedding in. The gauges used on the jacks had been tested daily on a dead-weight pressure-gauge tester.

The moulds for precasting the packing pieces had been machined to a tolerance of 1/64 in. and the top packings were standard $\frac{1}{4}$-in. and $\frac{1}{2}$-in. rolled steel plates. Variations in packing thickness were insignificant in comparison with the stretch of the cable. A tolerance of $\frac{1}{8}$-in. above or below the point at which correct tension was developed had been permitted.

Drilling conditions would vary greatly from one dam to another and the optimum size of hole would have to be determined for each site on its own merits. Smaller and closer-spaced holes had the merit of producing a better distribution of stress.

Cables had been transported to the dam in covered trucks but no other specific protection had been provided in transit. The period between manufacture and installation had been short.

The reinforcement of the jacking-heads comprised a three-dimensional grid of bars ranging from $\frac{1}{4}$ to $\frac{1}{2}$ in. dia., spaced from 4 to 6 in. apart. Particular attention had been given in the design to the possibility of splitting in the plane of the two cable runs.

The test to destruction on a prototype head had been carried out by Coyne and the actual conditions of failure were not known to the Authors.

With regard to Mr Buck's comments on the theory of anchorages and his reference to Mr Bank's experimental results, the Authors agreed that application of mathematical results to actual rock foundations should be made with caution and the basis of design adopted by Coyne accordingly was known and was intended to be conservative.

Mr Bogle had posed two interesting questions. The vertical drop adopted at Steenbras of about 15 ft was considered to be satisfactory but its extension to greater heights might well need further consideration. It was, however, not necessarily impossible to extend the method to that height; indeed the necessary extent of cantilevering on the upstream side to avoid a vertical drop might well be difficult to design satisfactorily in a major raising.

When the reservoir was empty, tension would develop on the downstream toe and theoretically cracking might appear on the downstream face. That effect was not considered to be serious since cracks on the downstream side would not give rise to increased

uplift and would be no more harmful than the existence of construction joints. There had in fact been no physical evidence at Steenbras of any tension cracking on the downstream face; but the reservoir had not been fully drawn down since raising had been completed.

Mr Shipway's point regarding the structural action of the dam was pertinent, but was not supported by observation of the dam. The arch thrust lines were apparently taken to the foundation in the straight blocks immediately adjacent to the curved part of the dam. The position of the inspection gallery was shown in Fig. 2 of reference 1, and is not considered to be sufficiently near the downstream side to offer evidence of the horizontal beam action contemplated by Mr Shipway; no evidence of such beam action was, in fact, detectable on or in the structure.

The Authors assured Mr Buchler that, so far as their experience extended, theoretical tensile stresses were not sufficient to cause detrimental cracking on the downstream face of the dam. In fact, no cracking which could be attributed to that cause had occurred since the completion of the raising. The suggested angle drilling for the cable holes to the tolerances required would certainly not be possible, and, even if it were technically possible, might well render such projects uneconomical.

The impact of the spillway overflow on the downstream face of the dam was not considered harmful and no additions, such as the lining suggested by Mr Buchler, had been made in that connexion. The Authors were not clear what limiting conditions Mr Buchler had in mind regarding the strengthening of existing dams by the method described in the Paper but, so far as the Authors were aware, no such limits had been reached in any project executed to date.

The Authors were inclined to agree with Mr Whysall that the Coyne method was in the near future likely to play a more important part in the raising and strengthening of dams than in the construction of new dams, and if a composite scheme was to be used it would undoubtedly be better to pre-plan for raising by the Coyne method when designing and constructing an initial gravity section. In the more distant future, however, it was considered that there were almost unlimited possibilities in new works, and some of them had recently been discussed by Professor R. H. Evans.[11]

The solution of the anchorage trouble mentioned by Mr Whysall was the indirect one implied in the Paper of avoiding anchorage in strata likely to cause deviation and enlargement of the hole, coupled with the other precautionary measures mentioned in the Paper.

The total cost to the City Council of the raising scheme was £110,000, and that was considered to be a better indication for future schemes than individual rates; obviously any important scheme would require individual consideration on both technical and economic grounds, and any information in that connexion was available from specialist contractors. However, in response to Mr Whysall's request, the following rates applied at Steenbras:

Drilling in concrete and rock: 14*s* to 25*s* per ft length of hole, 2½ in. dia., depending on depth (120 ft max.).
Supplying and grouting cables: 14*s* 6*d* per ft.
Supplying jacking head and stressing: £40 each (i.e., per pair of holes).

The Authors thanked Professor Robertson for the correction given in his contribution and were interested to learn that work on similar lines had been contemplated by him so long ago as 1926.

They agreed that absolute watertightness in the holes would be the ideal, though they believed that the specified maximum permissible leakage was sufficiently low to ensure satisfactory anchorage so far as that factor was concerned. They were confident that the causes described in the Paper were alone responsible for the failures which had occurred.

With reference to the query raised by Mr Clark regarding the final grouting-in of the cables, the Authors did not consider that any risk was involved in that respect. Grout placed under pressure did not suffer cracking or settlement of cement particles, as had

11 "Applications of prestressed concrete to water supply and drainage." Proc. Instn Civ. Engrs, Part III, vol. 4, p. 725 (Dec. 1955).

been amply demonstrated on many occasions by subsequent exposure of grout placed under such conditions.

With regard to what Mr Clark described as the factor of safety, there was of course no knowledge of the margin between the initial tension of 77 tons per cable and the ultimate strength of the cable and anchorage. However, it was considered that, in the circumstances described in the Paper, particularly the fact that every cable was initially tested to a load 10% in excess of the working load, adequate safety was ensured.

Care was taken prior to jacking to ensure that the cables were correctly centred on the jacking heads and, in view of the large extensions involved, the forces in the two cable legs could be assumed equal, except in the event of failure of the anchorage.

In reply to Mr Clark's final query, it could be stated that contractor's responsibility included the detailed design and construction of the works. There was no control in South Africa precisely corresponding to the United Kingdom Reservoirs Act, but all such works were subject to the investigation and approval of the provincial authorities prior to and during construction.

In reply to Mr Banks, no measurements were made of the deflexion of the dam after prestressing, primarily on account of the difficulty in measuring such small deflexions. As noted above, certain horizontal joint leakages ceased after stressing, and that indicated that some vertical deflexion had taken place; however, there was no significant evidence in the dam of lateral strain induced by prestressing. The anchorage test data provided by Mr Banks were of great interest and value, but, in the Authors' opinion, were not applicable to cables anchored in boreholes of small diameter.

# CORRESPONDENCE

## on a Paper published in Proceedings, Part I, March 1956

Paper No. 6114

## "The development of a mechanical-draught water-cooling tower"†

by

Lawrence Gilling Smith, M.I.C.E., and Gerald Johnstone Williamson, B.A., M.I.Mech.E.

### Correspondence

**Mr H. E. Eduljee** (Manager, National Peroxide Ltd, Bombay) observed that the data given in the Paper on the performance of 2-in. × 2-in. × ⅜-in. grid packing in industrial towers was very useful (see Table 1).

The "total-heat" method of designing cooling towers could be summarized by the equation:

$$c\int_{T_1}^{T_2} \frac{dT}{E_T - E_t} = \frac{K_a l}{L} = \text{N.T.U.} \qquad (1)$$

where $c$ denoted specific heat of water (= 1)
$E_T$ „ enthalpy of saturated air (B.Th.U/lb. of dry air) at water temperature $T$
$E_t$ „ enthalpy of air (B.Th.U./lb. of dry air) at air temperature $t$
$T_1$ and $T_2$ „ inlet and outlet water temperatures respectively (°F)
$K_a$ „ volume coefficient of transfer: lb/(hr × cu. ft of packing volume), (lb/lb.)
$l$ „ height of packing (ft)
$L$ „ water rate: lb/(hr × sq. ft cross-sectional area of tower)

By analogy with other diffusional processes, $K_a l/L$ is called the number of transfer units (N.T.U.).

The height of the packing divided by the N.T.U. would give the height per transfer unit (H.T.U.)

$$l/\text{N.T.U.} = \text{H.T.U.};\ \text{N.T.U.} \times \text{H.T.U.} = l \qquad (2)$$

Methods of integrating equation (1) had been discussed elsewhere[12] and it had also been shown that for film-type packings the H.T.U. could be correlated with the operating conditions by means of the equation:

$$\text{H.T.U.} = 0{\cdot}03(T_1 - 100) + m(L/G)^{0{\cdot}77} \qquad (3)$$

Where $G$ was the air rate, lb. of dry air/(hr × sq. ft cross-sectional area of tower), and $m$ was a constant characteristic of the packing.

† Proc. Instn Civ. Engrs, Part I, vol. 5, p. 86 (Mar. 1956).

[12] H. E. Eduljee and B. V. Raman, "The Design of Mechanical Draft Counter-Flow Water-Cooling Towers—III". Trans Indian Inst. Chem. Engrs, vol. 4 (1952), p. 32.

The Authors' data on their packing allowed a test of equation (3). If the equation held then $m$ should be a constant for all the runs (see Table 5).

TABLE 5

| $T_1$: °F | $T_2$: °F | Wet-bulb temperature: °F | $L/G$ | H.T.U. | $m$ |
|---|---|---|---|---|---|
| 68·0 | 60·3 | 49·9 | 0·96 | 4·28 | 5·40 |
| 80·0 | 70·8 | 61·8 | 0·96 | 4·52 | 5·30 |
| 81·3 | 71·0 | 61·5 | 0·872 | 4·55 | 5·66 |
| 72·5 | 62·1 | 53·0 | 0·685 | 3·86 | 6·26 |
| 75·5 | 57·6 | 41·3 | 0·680 | 3·98 | 6·35 |
| 96·4 | 73·7 | 50·5 | 1·138 | 7·23 | 6·64 |
| 80·6 | 65·1 | 43·1 | 1·123 | 4·89 | 5·02* |
| 88·8 | 73·4 | 52·5 | 1·13 | 6·37 | 6·10 |
| 89·0 | 69·9 | 61·2 | 0·755 | 4·08 | 5·48 |
| 77·9 | 59·9 | 43·7 | 0·807 | 4·56 | 6·15 |
| | | | | Average | 5·93 |

* Not included in average.

Equation (3) applied to that packing also, since the extreme values of $m$ fell (with one exception) within 12% of the average value. The performance equation for the 2-in. × 2-in. × $\frac{3}{8}$-in. grid packing was then:

$$\text{H.T.U.} = 0{\cdot}03(T_1 - 100) + 5{\cdot}93(L/G)^{0{\cdot}77} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Equation (4) was useful for three reasons:—

(a) The performance of the packing over a wide range of operating conditions could be expressed by a single equation.

(b) A preliminary calculation of the height of packing could be carried out rapidly; since equation (4) was based on actual test data the answer obtained would be reasonably correct. As an example, it was desired to cool water from 86·7 to 73·4°F with $L/G = 0{\cdot}868$ and a wet-bulb temperature of 62·8°F. The N.T.U. for those conditions was 1·375, and from equation (4) the H.T.U. was 4·95. The required height was therefore 1·375 × 4·95 = 6·8 ft; the Authors had actually used 6·0 ft of packing.

(c) When a new tower was tested, the test conditions seldom agreed closely with the design conditions. The problem then was to decide from the test data whether the tower would in fact work under design conditions. For the design data given in (b) above, the test data was: water cooled from 68·0 to 60·3°F with $L/G = 0{\cdot}96$ and a wet-bulb temperature of 49·9°F. From the test data the N.T.U. was 1·40 and the H.T.U. would be 6·0/1·4 = 5·24. Substituting that value of H.T.U., with $T_1 = 68{\cdot}0$ and $L/G = 0{\cdot}96$ in equation (3) gave $m = 5{\cdot}40$. The test equation for the packing was therefore:

$$\text{H.T.U.} = 0{\cdot}03(T_1 - 100) + 5{\cdot}4(L/G)^{0{\cdot}77}$$

For the design condition the N.T.U. was 1·375 and the H.T.U., calculated from the test equation, was 4·42. The height of packing required to carry out the design duty was therefore 1·375 × 4·42 = 6·08 ft. Since the actual packed height was 6·00 ft, the tower would carry out the design duty.

The value of $m$ was also indicative of the efficiency of the packing—the smaller the value,

the more efficient the packing as a transfer medium. For a complete evaluation of the packing its pressure-drop characteristics must, of course, also be taken into account.

**The Authors,** in reply, agreed that the "transfer unit" method of correlation reduced the work involved in preliminary design calculations. Mr Eduljee had presented a more refined version of the ordinary method, which improved accuracy. However, the Authors found that most tower designers evolved quick simple methods, and they would hesitate to advocate superiority for any particular method.

# CORRESPONDENCE

## on a Paper published in Proceedings, Part I, May 1956

Paper No. 6113

## "The experimental and mathematical analysis of arch dams, with special reference to Dokan" †

by

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### Correspondence

**Dr O. C. Zienkiewicz** (Lecturer, Department of Engineering, University of Edinburgh) observed that an examination of the stresses obtained by the Authors revealed rather small departures from linear distribution on practically all sections. That fact seemed to point towards the applicability of thin-shell theories when seeking a possible simplification of the laborious calculations involved in the exact analysis.

To find the order of approximation involved in such a simplification, the easiest way lay in the analysis by the thin-shell theory of the "tumbler" subjected to water-load conditions and a comparison of the results with those given in Figs 26d and 26e.

Fig. 50a showed the full section through the tumbler to be analysed. The essential assumption made in the shell theory was that the thickness of the arch $t$ was very small in relation to the radius $\bar{r}$. In fact the analysis was applicable to a thin shell (shown shaded in Fig. 50a) in which the thickness varied in the same way as that of the dam proper. It was to be expected that the errors in such an analogue would be greatest in the regions near the base where the $t/\bar{r}$ ratio was rather large. Since the thin-shell theory was obviously incapable of dealing with the local stress distributions due to the stepped part of the profile, a somewhat simplified variation of thickness was assumed in that region.

The equations governing the displacements of the shell reduced in that symmetrical case to a simple differential equation with one variable (the radial displacement $u$). In the notation adopted in the Paper that equation was[28]:

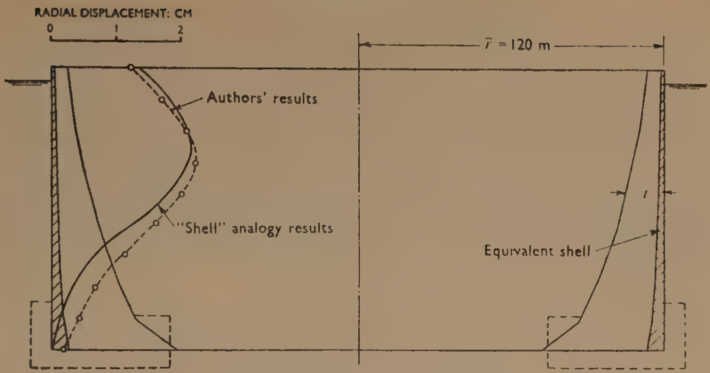
$$\frac{d^2}{dz^2}\left(t^3\frac{d^2u}{dz^2}\right)+t\frac{12(1-\sigma^2)}{\bar{r}^2}\,u = \frac{p}{E}12(1-\sigma^2)$$

The end conditions to be satisfied at the base, where full fixity was assumed were:

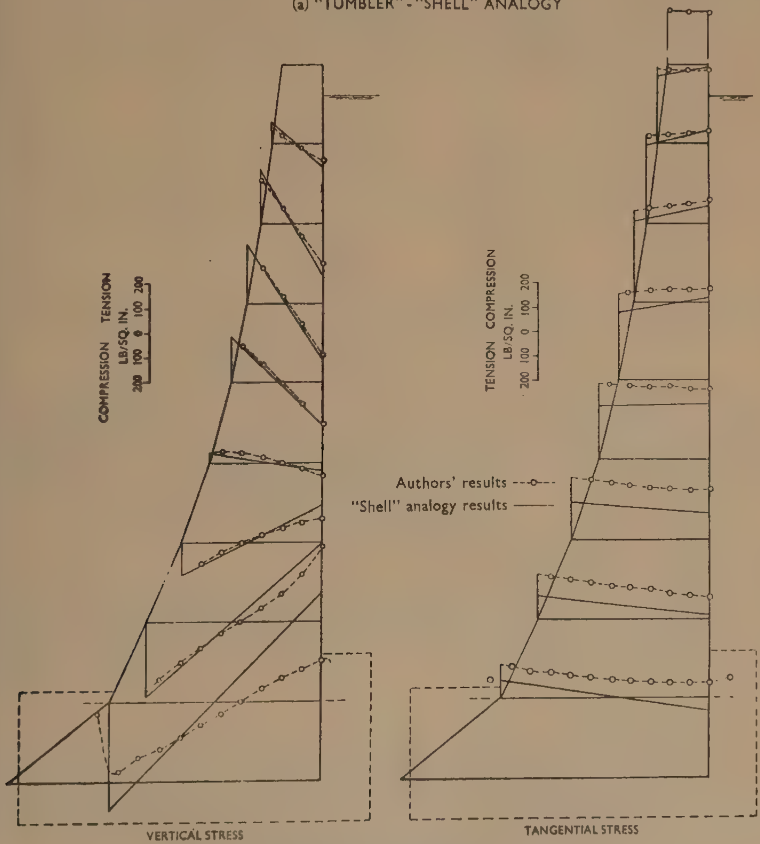
$$\frac{du}{dz} = u = 0$$

† Proc. Instn Civ. Engrs, Part I, vol. 5, p. 198 (May 1956).

[28] References 28–59 are given on p. 433.




(a) "TUMBLER"-"SHELL" ANALOGY




(b) COMPARISON OF STRESSES OBTAINED BY THE AUTHORS AND BY "SHELL" ANALOGY

("Tumbler" solution - water load only)

and at the top, where both the shear force and bending moment vanished:

$$\frac{d^3u}{dz^3} = \frac{d^2u}{dz^2} = 0$$

A formal solution of that equation was only known for either a constant or linearly varying thickness and hence the solution was obtained by writing down the appropriate finite-difference equations and applying the relaxation process. Only nine points were considered at levels corresponding to the even numbers of the grid adopted by the Authors. The computed radial displacements at those levels together with the resulting vertical and tangential stresses were given in Table 15. The values of stress were given only for the downstream and upstream faces since a linear distribution between those values was implied by the assumptions of the theory.

TABLE 15

| Grid level | Radial displacement: cm | Vertical stress: lb/sq. in. | | Tangential stress: lb/sq. in. | |
|---|---|---|---|---|---|
| | | Downstream face | Upstream face | Downstream face | Upstream face |
| 0 | 1·27 | 0 | 0 | − 212 | − 212 |
| 2 | 1·77 | 83 | − 83 | − 281 | − 305 |
| 4 | 2·09 | 203 | − 203 | − 316 | − 378 |
| 6 | 2·09 | 238 | − 238 | − 311 | − 383 |
| 8 | 1·78 | 177 | − 177 | − 269 | − 321 |
| 10 | 1·28 | 34 | − 34 | − 208 | − 218 |
| 12 | 0·75 | − 144 | 144 | − 145 | − 103 |
| 14 | 0·32 | − 302 | 302 | − 98 | − 8 |
| 16 | 0·06 | − 434 | 434 | − 75 | 55 |
| 18 | 0 | − 320 | 320 | − 48 | 48 |

Tension positive; compression negative

For comparison the displacements were plotted in Fig. 50a side by side with those obtained by the Authors. In Fig. 50b a graphical comparison was made between the stresses calculated by the thin-shell theory and those given in Figs 26d and 26e. That comparison showed a surprisingly good agreement at all except the base sections—especially since in neither case was the relaxation carried out to the limits of accuracy.

The computation necessary for the "shell" theory calculations of that case was accomplished within 3 days—a time undoubtedly much shorter than that required for the accurate analysis in two dimensions.

That success in the "shell" approximation for the tumbler analysis led to the expectation of similar accuracy and reduction of labour in the solution of the full problem including the abutment effects. That work was now being undertaken and the full solution obtained by the Authors would prove of inestimable value as a standard against which the attainable could be checked.

**Dr Serge Leliavsky** (Consultant) observed that the investigation described in the Paper was an interesting attempt to replace the usual calculation methods by the equations of mathematical elasticity. The mathematics, as well as the experimental technique, of the solution presented were beyond praise, but he had shown elsewhere[29] that the main difficulty in deriving significant conclusions from such calculations lay in the permissible stress criteria to be applied in connexion therewith.

That was especially true about the "particular points of the field", in which, according to the theory of elasticity, the stresses rose to infinity under all conditions—whatever the dimensions or loading of the investigated dam. It was, indeed, the tragic fate of that method that the heel and toe of the profile of the dam were among such points. It followed

that the stress condition, at the critical points which the designer used to draw conclusions about the safety of the profile, could not be determined by the methods of pure mathematical elasticity, and that might explain (at least, partly) the reason why those methods were seldom, if ever, applied in practice. In fact, granted a certain mathematical ability and a sufficiently large staff of computers to carry out the voluminous arithmetic, there was, apparently, no reason why the method should not be used for design purposes more often—were it not for the problem of particular points and stress criteria.

It might, therefore, be relevant to consider the solutions of that particular problem, as adopted in the earlier attempts to apply mathematical elasticity to dam design.

It seemed that attention had first been drawn to the problem in the technical press in connexion with the experiments of Ottley and Brightmore[30] in 1908, but the suggestion, made at the time, of using steel bars at the heel of a gravity dam, to counteract the alleged theoretical stress concentrations created at that point, had never been put into practice.

In another case—that of Richardson's solution of elastic equations by the finite-difference method[31]—the sharp re-entrant corners of the profile of the dam were assumed to be bevelled. Thus the problem was by-passed, rather than solved, which however was fully admissible, for Richardson's results were not meant to be used for the design of a certain, particular dam, but were solely intended to throw more light on the debatable points of the controversy which arose at that time in connexion with Karl Pearson's theory.

In more recent times, the theory of elasticity was employed for the calculation of stresses in dams by Brahtz.[32] Since the object of that attempt was a design problem—i.e., testing the profiles of several high dams built by the U.S.A. Bureau of Reclamation—the stresses at the critical points could not be altogether disregarded. The following artifice was therefore employed—the re-entrant corners were assumed to be provided with imaginary fillets with curvatures large enough to keep the theoretical stresses within the elastic limit of the material.

The practical value of the procedure might, perhaps, be subject to doubt; which, by the way, was openly admitted by its author who stated that the results thus obtained were not supposed to be used as a criterion for design; however, since he used them as such, the statement appeared to be rather ambiguous.

It was possibly a significant point that such an ambiguous equivocal attitude was not an exception among those who had dealt with the same problem in the past.

Turning now to the present Paper, it was stated on pp. 224 and 225 that the very high stresses obtained by the elasticity method for the re-entrant corners would be much smaller in practice, because in actual work the corners were not so sharp as they were assumed to be in theory, and, also, because those stresses would be relieved by the creep of the concrete.

The finality of the statement deserved praise, but whether it would be accepted unconditionally by the designers was not certain. There might, in fact, be various questions arising in connexion with that theory. Infinite results, when obtained in other branches of engineering research—for instance in the calculation of the gradient for enforced percolation beneath a flat foundation—were sometimes symptomatic of a danger zone, which was occasionally considered to be a sufficiently important consideration for giving up the type altogether.

In the Authors' calculation the intensities of the stresses at re-entrant angles depended entirely on the distances between the apexes of those angles and the nearest nodes of the grid, but judging by Brahtz's diagrams, which were obtained by the photo-elastic method, those high stresses were not so localized as postulated by the Authors, and that meant that the relief due to creep was not a *prima facie* case. It must also be remembered that in elastic slab model tests, which were continued to destruction, the first cracks tended to appear at the re-entrant angle at the heel of the dam.[33]

On the other hand, it was scarcely possible to admit that, taking into account the reduction scale, the re-entrant angles in the models tested by the photo-elastic method were a more perfect image of theory than the actual dam.

Faced with all those problems, the practising man might well conceive certain doubts as to the reliability of a solution which yielded obviously wrong (and even impossible) results for the most dangerous points of the design pattern. More explicit information on the subject might therefore contribute to the better understanding of the whole problem. In particular, the Authors' attention was directed to an apparent inconsistency between the statement (see p. 225) that "The stresses quoted . . . are as given by the calculations and no allowance has been made either for the deliberate provision of fillets or for the effect of creep" and the fact that in Table 10 the stresses were calculated "allowing for the fillets on the air face" (see p. 224). If that was an exception, its argument deserved, possibly, being stated in full.

After all, from the standpoint of the designer the fact that the algebraic sum of the stresses given in Figs 26e and 27 for the upstream footing was 300 − 190 = 110 lb/sq. in. in tension, might appear to be the predominant consideration, and every step must therefore be taken to appease any doubts he might have on the subject.

That was why, in the foregoing remarks, Dr Leliavsky had attempted to explain more clearly the argument of the "particular points" of a field.

In regard to the stress calculation itself, attention would first be directed to the preliminary method referred to in the Paper as the "tumbler" solution. Dr Leliavsky believed that more emphasis must be laid on that earlier stage of the calculations, because the actual design of the final profile of the Dokan Dam apparently depended on it (see p. 206)—the more elaborate stress analysis, which was particularly carefully described by the Authors, coming only in the way of a verification. Thus, although the latter might be (and obviously was) the main centre of interest of the Authors, Dr Leliavsky, as a designer, was also interested in the preliminary (but decisive) phase of the stress analysis. He ventured to suggest that certain points relating to that phase might possibly gain by being more explicitly stated.

In the first instance, why was it that no advantage was taken (at least as a preliminary step) in that calculation of the numerous formulae employed in designing thousands of existing cylindrical reinforced concrete water-tanks.[34–36]

The analogy between the two problems was very close. Both cases were concerned with elastic cylindrical shells encastré at the bottom, and the fact that the pressure was directed outwards in one case and inwards in the other did not really matter. Apart from that, one of the more obvious advantages of the current tank formulae was that it was so easy, in using them, to assess the quantitative effect of the various assumptions regarding the rigidity (or otherwise) of the fixation of the shell at the bottom.

It was therefore scarcely surprising that the use of formulae originally devised for tanks, in connexion with the theory of arch dams, had already been envisaged in America.[37]

Since, however, the Authors had developed and applied an original procedure of the type of relaxation methods, and since for a given stress limit the results depended solely on the radius and water depth—but not on the length or angle of the dam—it was by no means impossible to represent those results in the form of a set of more general diagrams, giving the required dam thicknesses as functions of the depths below the assumed reservoir level, for various given radii. The work performed by the Authors would thus be made use of for much wider objectives than the Dokan Dam alone.

On the other hand, it would be of considerable interest to publish in full the *quantitative* information on the difference between that method and the method of "independent arches" (p. 223).

Although the Paper contained abundant information on the method and results of the stress calculation carried out by the Authors, very little was said about the safe limits believed to be consistent with those stresses. That was possibly regrettable, because the same limits which were commonly employed in conjunction with the usual calculation, were obviously not applicable in connexion with the Authors' method.

It was stated on p. 206 that profile D.1 was given up because approximate calculations indicated that it was likely to be rather highly stressed. It would certainly be interesting to know the stress which was considered as being too high.

In Table 13 the vertical tension in the concrete was given as 200 lb/sq. in., which was apparently assumed to be safe. Since the Authors took the trouble to calculate and quote that stress, they probably had an idea of the particular stress intensity to be taken as the limit under such assumptions. For instance, should a tensile stress of 250 lb/sq. in. or 300 lb/sq. in. be still taken as safe, or was that already too high?

The reason for raising those questions was that the limits commonly adopted for the usual calculation method were not valid for the Authors' solution.

What, then, was the fundamental difference between the solution described in those pages as the "usual method" and the stress calculation as carried out by the Authors. That would be the first point to be raised by designers. In fact, since both methods were basically derived from the same "elastic principle," what then were the points in which they disagreed?

In attempting the general principle of the solution described as the usual method, attention was called to the fact that one of the most helpful tools in the hands of the engineering designer was the artifice of dividing the stresses into two groups, primary and secondary, the former being taken into account quantitatively in the calculation of resistance, whilst the latter group were covered by a factor of safety. For instance, in designing a lattice girder, the axial stresses in its members were considered to belong to the first group, whereas the bending stresses due to the rigidity of the joints were usually relegated to the second category. The choice depended largely on the assumed structural mechanism of the unit investigated; for instance the stresses which were supposed to belong to the secondary class in calculating a lattice girder would be taken as primary stresses when designing a girder of the Vierendeel type.

If the history of the evolution of the arch dam was examined from that particular standpoint, it would be observed that arch stresses only were included in the primary group, when the earliest dams of that type were designed (in Australia). Later on, however, the cantilever stresses were added, and the concept prevailed for quite a long period. Since in that case there were two types of primary stresses the part of the load taken by either type was a hyperstatical problem, which was frequently solved by the "trial load" method.

In still more recent times other types of stresses, e.g., torsion, were also considered as participating in carrying the load—as shown for instance in Fig. 51, abstracted from a

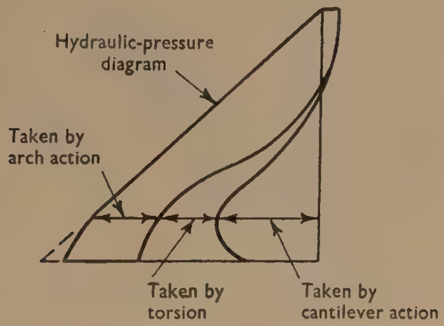



FIG. 51

recent Swiss publication[38]—but in all those cases the primary stresses were still confined to a certain limited number of types.

On the other hand the calculation carried out by the Authors according to the equations of elasticity aimed, in principle, at all stresses without exception, and its practical application therefore needed a new value for the coefficient of safety, or, which meant the same, a new stress limit, specifically determined for that particular type of calculation.

Earlier references to the stresses at the heel and toe of the dam would have sufficed to illustrate the point of the foregoing argument, but the analogy with the lattice girder might also be used to explain the problem more clearly; in fact, the commonly applied stress limits for the design of such girders were for axial stresses alone. However, if the fixation stresses (i.e., the bending stresses consequent on the rigidity of the joints) were also included as primary stresses, the usual limits would be largely exceeded, and thousands of existing bridges would therefore appear to be unsafe in spite of the fact that they were performing their duty perfectly well. Such an alteration—or improvement—in the calculation method therefore called for a corresponding alteration in the adopted limits.

Academically, the perfection of the Authors' method could not be doubted, but its significance as a design implement depended entirely on the stress limits to be used in connexion with it; whether those were the same limits as in the usual design methods was an open question.

Experience with numerous designs was the only manner to solve that problem in general. But a step towards a solution would be reached if the Authors could produce for the same dam a set of stresses calculated by the "trial load" method, or better still, produce the results of the application of their own method to a number of existing dams.

That, in fact, was the solution resorted to by Sazilly and Delocre, when they first applied Navier's principle to the design of dams. The new limits were then determined in that manner.

Comparing the heading on p. 202 ("The trial-load method") with the relevant pages of the text, it followed that the only rock deformations considered by the Authors were those

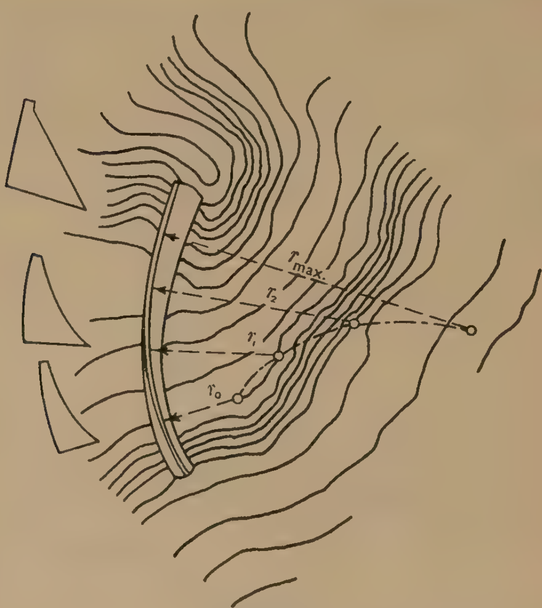



FIG. 52

which arose from direct contact with the dam. That assumption did not agree entirely with the facts. Seasonal rock displacements downstream of the dam were observed by Juillard in Switzerland, at distances from the dam and reservoir which precluded attributing them to direct contacts. The only explanation thus far produced was interstitial water action correlated with seepage.

It was true that such deformations were not taken into account when arch dams were designed for the usual type of rock formations, but the site of the Dokan Dam could not accurately be described as a usual type. In fact, it was not a very good choice, for though on the right side of the dam the rock was a solid wall of substantial proportions, on the left side (judging by Figs 1 and 3) there was a thin tongue or peninsula projecting far into the valley. Although the peninsular formation was chiefly discernible in the upper layers of the mountain, it was quite probable that the whole structure of the rock in its neighbourhood would be subjected to movements of the Juillard type and the abutment might then move away from the dam.

There must have been good reasons for choosing such a site for an arch dam. That aspect of the problem was, however, beyond the scope of the Paper. Sir Benjamin Baker's words on the subject might be remembered—to the effect that whilst an engineer was perfectly able to design a dam which would be safe, he could not predict the moment at which an unsafe dam would fail.

Hence, should it be required to adjust the arrangement of an arch dam to a difficult site, the principle of the design must be modified accordingly. The first suggestion might be to revert to the gravity type, but that would mean shear waste of money in so far as the right rock-abutment was concerned. A mixed type (see Fig. 52) could, however, be imagined, with a gradually varying radius, starting with a minimum value $r_0$ at the right side of the valley and ending with $r_{\max.}$ as a maximum (infinity?) at the left abutment. The very large (almost infinite) rigidity of the dam in a direction parallel to its axis, would then take the place of an abutment.

It was realized that that suggestion was too advanced at the present moment and might possibly be considered paradoxical, but the principle of adjusting the radius of an arch dam to the relative rigidities of the abutments deserved perhaps being placed on record.

**Professor Dr Ing. Angelo Berio** (Director, Institute of Building Science, Polytechnic School, Cagliari, Italy) remarked that in the first part of the Paper the Authors had courageously rejected the current hypothesis, which tried to assimilate an arch dam to a thin shell. They had on the contrary, undoubtedly accepting the fact that one was dealing with a solid of revolution, developed the calculations from the general equations of elasticity. The equations had been resolved by the relaxation method, on the hypothesis of the theoretical anchoring of the foundation along its whole length in the two cases considered—of a closed wall and of an actual reservoir—and a simple examination of the results was quite sufficient to justify that strict manner of undertaking the calculations: one could see at once that there were many parts of the dam regarding which the hypothesis of calculation as a shell proved its insufficiency without question.

In that respect one must therefore recognize the usefulness of the work done, regretting however, that the undeniable possibility of deformation of the foundation course had not been considered. The research in question, extended very strictly to three dimensions, was in consequence much more accurate than any of the methods derived from the theory of shells or of the behaviour of wall arches, even including the Trial Load Method; and that consideration justified without difficulty the exceptional scope of the work. However, it would be most useful—there being no question of making such an extended research on each occasion—to use the results of that calculation for checking the simplified methods (Ludin[39], Ritter[40], *et al.* [41, 42]) in order to deduce some practical conclusions regarding the lack of precision that might be expected from their adoption in lieu of a more correct process.

The second experimental part of the work seemed to be very interesting, particularly if the Authors would proceed with it up to the knowledge of the experimental stresses, which might then be compared with the results of calculations. The experimental technique adopted for the tests on the reduced models of the Dokan dam, based on the use of a material having a very low Young's modulus such as rubber, made it possible to simplify the apparatus for placing it under load and permitted the optical measurement of the displacements. The material used had, of course, a Poisson's ratio quite different from the one for concrete; but that defect, fully recognized by the Authors, who had even tried to

estimate its importance, was common to plastic materials, which were much used in the construction of scale models in Portugal and in Italy.[44–47] In Italy the experimental testing technique on reduced-scale models was often very different: rather than "flexible" scale models there was frequently a preference for the construction of small real dams in concrete (scale 1 : 40 or larger), which could be loaded to destruction. However, the Italians felt the need for a well defined technique, quicker and less costly, which would help in the first stage (while still "fluid") of the design for a dam. In that respect, besides the process developed by Mr Torroja, the tests in question could also be of help.

The Authors were to be thanked for making available the complete results of the calculations and tests, because it was only by the study of a great fund of practical results that engineers could hope to learn and know the true static behaviour of dams. It was with that end in view that Professor Berio submitted a list of reports relating to tests made in Italy on scale models of dams.[48–52]

**Professor A. L. L. Baker** (Professor of Concrete Technology, Imperial College of Science and Technology) said the Authors stated that the complete solution of the stress equations under carefully specified conditions provided a valuable standard by which approximate methods of analysis could be judged. In that sense, the Paper was a valuable guide to all future dam designers, who might otherwise have been in doubt as to whether stress distributions in detail were such as would be expected, or whether unsuspected local concentrations could occur which might be dangerous.

The Authors also stated that further research was intended in order to establish preliminary design methods of a reasonably simple type. In that connexion, it was important to determine the various possible worst conditions of load in conjunction with differential temperature, shrinkage, creep, and abutment yield, and the possible magnitude of the resulting additional stresses. For example, one critical set of conditions in regard to cantilever tension on the upstream face might be the simultaneous action of maximum

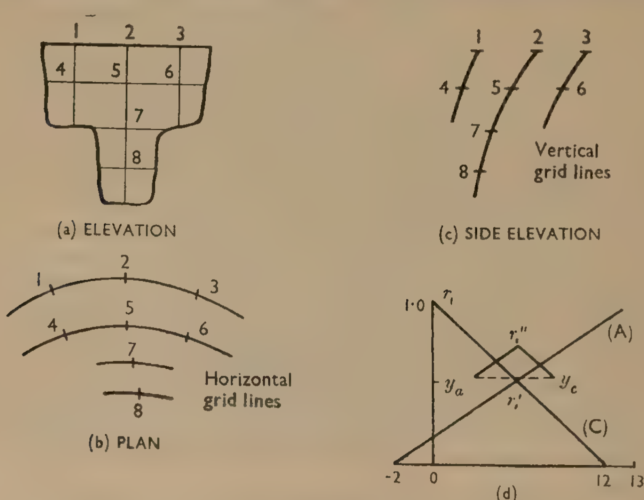



FIG. 53

water pressure, earthquake shock acting downstream, maximum horizontal shrinkage, creep contraction, and arch abutment yield in the thin upper part of the dam, and minimum horizontal shrinkage creep and abutment yield in the thick lower part of the dam, together with a maximum reduction in temperature in the thin upper part compared with the thick lower part. The arch at the top would then tend to become slack and transfer

load to the vertical cantilevers in the middle of the dam, which might thereby develop vertical tension in the upstream face at about half-depth. Such possible extremes of load and differential contraction of the concrete, and movement of the abutments and foundations might prove to be the major considerations governing the design. Since such values could only be assessed approximately and time was usually limited, it might be wiser to use an approximate simple method of calculation rather than a precise one, but applied to several possible conditions of differential contraction and support movement. The dam might be considered to act as a grid of intersecting arches and cantilevers having negligible resistance in torsion.

The following trial-and-adjustment procedure often quickly converged to a sufficiently accurate solution in distributing load to the members of a grid—neglecting torsion acting at the intersections, Poisson's ratio effects, and, in the case of a dam, the effect of differential vertical compression.

Figs 53a, b, and c showed the centre-lines of vertical and horizontal strips of unit width of an arch dam. It was assumed that the horizontal water pressure on a square of unit width acted on the two members at each intersection, together with (in the opposite direction) the horizontal force required to restrain movement of the vertical cantilever strip due to dead load when each cantilever was assumed to be freely hinged at each horizontal intersection. If at each intersection such as the $n^{th}$, $r_n$ times the resultant horizontal load acted on the arch strip and $1 - r_n$ times the resultant horizontal load acted on the cantilever strip, then the deflexion of the cantilever and arch at each intersection ($y_n$ being the deflexion of arch or cantilever at intersection $n$, the influence coefficients being indicated by typical numerical values) could be expressed as followed:

For the arches:
$$y_1 = 10r_1 + 3r_2 - 2r_3$$
$$y_2 = -r_1 + 15r_2 - r_3$$
etc.

For the cantilevers:
$$y_1 = 10(1 - r_1) + 2(1 - r_4)$$
$$y_2 = 20(1 - r_2) + 15(1 - r_5) + 10(1 - r_7) + 2(1 - r_8)$$
etc.

The figures were influence coefficients for horizontal deflexion for each point on each strip due to the total horizontal load acting at each other point. The coefficients could be worked out and their value depended only on the total horizontal load at such points and on the elastic characteristics of the strip. In the case of the arches, when desired, temperature, shrinkage, creep, and support contractions might be assumed giving additional deflexion at each point. Successive approximations of the values of $r$ at each intersection might be found as followed. Referring to Fig. 53d for intersection (1); the line (A) was obtained by joining the maximum and minimum possible values of $y_1$ for the arch strip, namely:

when $r_1$ and $r_2 = 1$, and $r_3 = 0$; $y_1 = 13$
and when $r_1$ and $r_2 = 0$, and $r_3 = 1$; $y_1 = -2$

Similarly, the line (C) was obtained by joining the maximum and minimum possible values of $y$ for the cantilever strip, i.e., say for point (1):

when $r_1$ and $r_4 = 0$; $y_1 = 12$
when $r_1$ and $r_4 = 1$; $y_1 = 0$

The intersection of the lines (A) and (C) gave the first approximate value of $r_1$, i.e., point $r_1'$ (Fig. 53d). First approximate values of $r_2$, $r_3$, etc., could be obtained similarly, using a separate diagram for each intersection. The first approximate $r$ values were then substituted in the equations for each intersection and the values of $y$ obtained for the arch and cantilever were plotted as at $y_a$ and $y_c$ (Fig. 53d) for intersection (1). The second approximate value of $r_1$, namely, $r_1''$ was then obtained by drawing lines from $y_a$ and $y_c$ parallel to lines (A) and (C) respectively (see Fig. 53d). That procedure was followed for each intersection and repeated for $r_1''$ in the same way as for $r_1'$, etc., until the cantilever and arch deflexions became sufficiently close.

**Mr C. Snell** (Lecturer, Civil Engineering Department, University College) observed that the mathematical treatment presented in the Paper was a monumental piece of "relaxation" and, as the first analysis of a perfectly general three-dimensional stress system, marked a significant step forward in the application of that method.

When considering the thermal stresses, it appeared that the steady state temperature had been obtained for the mean temperature on the boundaries and for the maximum variation (Figs 29a and 29b). The stresses were then calculated for the maximum, mean, and minimum steady states of temperature distributions. In such problems as steam entry into steam mains or steam turbines, or even washing china or glass in hot water, the dangerous stresses were usually associated with the maximum temperature gradients and the maximum time rate of change of temperature. Were there any special reasons other than that of mathematical simplicity which led the Authors to consider the steady state temperature? The formulation of the problem of thermal stresses in axisymmetric solids used in the Paper was presented in a Paper by members of the Mechanical Engineering Department of the Imperial College of Science and Technology to a meeting of the Stress Analysis Group of the Institute of Physics, and was summarized in Aircraft Engineering.[53] It would be interesting to hear of their experience in computing thermal stresses for various stages before the steady state of temperature was reached.

The vertical mesh length was given on p. 204 as 12·4 m and the radial mesh length as 6·2 m, but comparing Fig. 5 with Fig. 26 mesh distances appeared to be half those amounts. It would appear that a "smaller mesh" had not been used in that analysis. Had the Authors considered the size of the mesh in relation to such local stress raising features as the change in section at point C (Fig. 32)? A complete photo-elastic test of the dam would take several months, but tests on the section of Fig. 26e loaded two dimensionally as a cantilever showed a stress concentration factor at C of between 1·5 and 2 depending on the position of the load. Fig. 54 showed a typical fringe pattern for bending with shear. Two mesh lines were shown on Fig. 54. On the face CD, over a distance of half the vertical mesh size the elastic tensile stress was increased by more than half, and for one-sixth of

FIG. 54

the mesh size that stress was doubled owing to the local effect of the change of section at C. That local disturbance would penetrate to a depth of about one-sixth of the vertical mesh size. There was no reason why a three-dimensional body should not show a similar stress concentration. With that factor the tensile $\widehat{zz}$ stress due to water load would exceed the compression due to gravity for several metres on the water face. Whether that was significant was a matter for the engineer, taking all matters into consideration. It must be emphasized that those stresses were the stresses that would exist in a perfectly elastic material, as also were the stresses obtained by calculation.

**Mr Jan A. Veltrop** (Design Engineer, Harza Engineering Co., Chicago, Illinois) remarked that the Paper presented not only a new solution to the complicated problem of arch-dam analysis, but it was also an important contribution to the already wide and steadily growing field of application of the "relaxation" method.

Mr Veltrop discussed the advantage of the "relaxation" method compared with the "trial-load" method; also the development of an approximate method, and the importance of model tests.

He observed that of the several available methods only the "trial load" analysis could be compared with the "relaxation" method. None of the other methods included non-linear stress distribution, the influence of haunches near the abutments, and the effects of tangential and rotational movements on the stress distribution throughout the dam. However, the usefulness of the relaxation analysis was rather limited. Was the dam considered symmetrical in the final analysis on the basis of model tests only? Were the moduli of elasticity of concrete and rock assumed equal mainly to simplify the analysis? It would seem that the consideration of arches with variable thickness, as well as the use of different moduli of elasticity led to a large increase of the amount of work, since the number of different space lattices needed in the relaxation procedure increased considerably. Would the Authors comment on that? It was noted that both effects had been included in the application of the "trial load" analysis.

It was common practice in the design of arch dams to account for the plastic flow in concrete by assuming a decrease in the modulus of elasticity. Such a decrease tended to keep the temperature stresses small. Nevertheless, a maximum vertical tensile stress of 200 lb/sq. in. was computed. For values above about 100 lb/sq. in. it was common practice in the United States to assume a cracked section. The difficulty in such cases was to determine the depth of the crack. In the "trial load" analysis the computations of cracks in cantilevers was considerably simplified by Tables for cracked sections. It appeared very difficult, if not impossible, to include the existence of cracks in the relaxation analysis. One would probably have to accept stresses up to a much higher limit, or change the dimensions and proceed with a new analysis.

That led to Mr Veltrop's second point, namely, the use of approximate methods. Analyses as time consuming as the Authors' relaxation method and the amplified version of the "trial load" method of the United States Bureau of Reclamation (U.S.B.R.) could only be justified for a final check on the stresses. It was therefore highly desirable to use a much shorter method for preliminary analysis, which could not only be repeated often without consuming too much time, but which also predicted the stresses within a reasonable limit of accuracy. For instance, in the case of tensile stresses that meant that one should expect stresses not to exceed 100 lb/sq. in. in the final calculation, if the preliminary analysis showed about zero tension. The U.S.B.R. developed the abbreviated version of the "trial load" analysis partly for that purpose, although in certain cases that method was considered accurate enough for final analysis. There were many less refined methods available, e.g., a method developed by Parme,[54] for symmetrical encastré arches with variable and constant thickness. There the arch deflexions at the crown of the individual horizontal arches were equated with those of the crown cantilever, the latter being either fixed or hinged at the base. Such a method could be improved upon significantly if the elasticity of the abutments and foundations was considered. Without going into further detail it was merely noted that the use of Tables for constant-thickness arches, prepared

by the U.S.B.R. for the abbreviated method, simplified such a computation considerably. The use of the crown cantilever in such an approximate analysis was important, since it eliminated the discontinuity between the radial deflexions of the individual arches at the crown, which was at the most important location along the arch.

The approximate method identified by the Authors as the "tumbler" solution considered a vertical element as part of a circular cylindrical body, symmetrically loaded. As was noted on p. 205, the results gave a good estimate of the vertical stresses but the hoop stresses were not acceptable. A comparison of the results of the hoop stresses could be obtained from Figs 26d, Plate 1, and 34b, Plate 4. The discrepancy for the hoop stresses might be explained as followed. The "tumbler" method, over and above the method of independent arches, had the distinct advantage of considering vertical cantilever action, since the tumbler was fixed at its base. Thereby the water load was distributed between arch and cantilever action. However, it was not likely that the correct distribution would be obtained by the "tumbler" method, because the end conditions of the horizontal arches were violated. In the "tumbler" method those points were allowed to move in radially, which did not agree with the actual situation. The above-mentioned crown cantilever method did not have that disadvantage, and probably took considerably less time than the "tumbler" solution. The argument might also be put as followed: if a certain number of vertical elements were analysed with the "tumbler" method then there did not seem to be a guarantee that at some elevation, other than the base, the radial deflexions would fit a pattern compatible with the deflexion of the horizontal arch-ring at that same elevation.

In view of the importance of the crown cantilever in providing a radial adjustment between the various horizontal arches, the lack of an equivalent correction to give radial adjustment for the various vertical elements would seem a real shortcoming of the "tumbler" method. From the reference to the use of the method of independent arch action on p. 223, it appeared that the Authors had not considered the importance of introducing a crown cantilever, or that they did not consider the temperature computations important enough to make that correction.

The Authors noted that for the "relaxation" method it was important to start with values in the grid that were at least reasonably close to the final result. In that connexion, were the results of the tumbler method useful, or had the Authors relied entirely upon measurements on the last model? The mould for the final model was shown in Fig. 13—was that model attached to rubber or to a rigid base? In the latter case, were the added rubber masses at the abutments and the foundation of the model large enough to account for the elastic behaviour of the actual rock at the dam site?

The Authors mentioned that the work extended over a period of 3 years. Was it possible to break that figure down and provide some approximate information on the number of man-months spent on the development of that new method and, separately, the time needed for the "tumbler" as well as the final analysis? Would the Authors expect any great saving of time if they were to perform a similar analysis on another structure?

**Mr J. Laginha Serafim** (Research Engineer, Head of Dams Studies Section at the Laboratório Nacional de Engenharia Civil, Lisbon) arranged his remarks under three headings: mathematical analysis, tests, and comparison of results.

*Mathematical analysis.*—All who had followed the slow progress of the calculation methods for arch dams would have learnt with pleasure of the work carried out in connexion with Dokan Dam, since it could be considered a decisive step towards the accurate solution of the problem. The principles now developed for the calculation of stresses were based directly on the equations of the theory of elasticity; that meant that the hypotheses of the strength of materials, especially that which referred to the linear distribution of stresses, had been abandoned. It was that hypothesis which up to the present had been the basis both of the methods depending on the distribution of loads between two sets of elements cut from the dam, such as Stucki's, the "trial load" method, that of Bosshart, etc., and of those based on the shell theory, such as Westergaard's, Toelke's, Arredi's, Berio's, etc.[55]

The Paper not only presented a more accurate method of calculating arch dams but also demonstrated that any three-dimensional problem of elasticity was capable of practical solution. No doubt that achievement owed its success to the development of numerical methods for the solution of differential equations, to which the English experience about "relaxation" methods had made a valuable contribution. The theoretical simplicity of those methods appeared to be the primary reason for their potentiality and range.

The Authors said their objective was to draw up a standard by which approximate and simplified calculation methods could be judged and also developed. However, Mr Serafim believed that the approximate methods could not be universally accepted for the calculations of arch dams. For example, it was clear that the "tumbler" solution dealt with by the Authors would not be suitable as the basis for a method, since the values of the stresses would be equal for all dams having the same central profile and the same curvature, whatever the shape of the valley and its singularities might be. Thus the determination of the stresses in the structures might continue to be a specialized work whether the "trial load" method was used, the "relaxation" method, or models.

If the dam studied had a double curvature and the radii of the arches were very different from the top to the bottom, or if the dam had openings or other singularities, the numerical solution would be much more difficult as soon as the equations relating stresses and displacements and the mesh became more complicated or the boundary conditions to be obeyed became more numerous. Of course, the increased difficulty of the application of the calculation methods when the dam had singularities or complex shapes was common to all the analytical methods, whatever they might be. But that was not so with models,* since in those the determination of the stresses required the same work whether or not the dam was symmetrical, had singularities, or had homogeneous foundations.

With regard to the calculations of the stresses due to thermal effects, the thermal phenomena occurring in dams were not satisfactorily taken into consideration in the Paper. In fact the difference between the two steady states of temperature considered corresponded to temperature variations inside the concrete which were too severe and never occurred. In Portugal the temperature variations were determined by studying the unsteady flow of heat, taking into account on the one hand the dissipation of the hydration heat and, on the other, the sinusoidal variations of the air and water temperature.

*Tests.*—With regard to the models tested, Mr Serafim stressed that in using materials having a Poisson's ratio of 0·5 an important similarity requirement was not fulfilled. In comparisons between models having Poisson's ratios of 0·2 and 0·5,[55, 56] it was found that the stresses in all regions of the dam far from the abutments were not significantly different and that in the regions round the abutments (especially the secondary principal stresses) they were. On the contrary, in those regions it was the strains which underwent small alterations owing to variations of Poisson's ratio. That was one of the reasons why the Laboratório Nacional de Engenharia Civil (L.N.E.C.) had recently put aside materials having a high Poisson's ratio, such as plastics, even though they might have a low modulus of elasticity, which was convenient for tests. Since the Authors only determined the displacements in the models it was doubtful if reliable stress values could be obtained by means of them because displacements gave strains and those were greatly influenced by the Poisson's ratio in nearly the whole dam.

If the stresses had not been determined in a model, the study could not be considered complete. It appeared then that an attempt should be made to measure them, in order to arrive at a better evaluation of the results obtained by the Authors. Furthermore, it was not considered easy to obtain the stresses in the models from the displacements as soon as that demanded high precision measurements and a knowledge of inside displacements.

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* In a Paper presented by Mr Serafim and others for the Symposium on Arch Dams of the American Society of Civil Engineers, to be held in June 1956, it was shown how models made it possible to determine the stresses in singular regions and for singular shapes of various Portuguese arch dams.

The methods given for determining the stresses due to the weight of the structure (immersion and inversion) had been in use for some time in the L.N.E.C.[56]

The conclusions relating to symmetry of the dam obtained through the measurements of displacements should not be taken too far, since Mr Serafim had verified asymmetry in dams, perhaps more symmetrical than that at Dokan, when taking stress measurements. In fact, the stresses could be considerably asymmetric whilst the displacements were only slightly so.

Curves of radial displacements at various levels, showing that it was the last few metres of reservoir water which had the greatest effect, had also been published.[57, 58]

*Comparison of results.*—It appeared that the introduction of the correction factor, given on p. 227, was arbitrary and the explanation given was not entirely satisfactory. In those conditions it would only be possible to carry out a conclusive comparison of results when Poisson's ratio for the model and for the calculation were the same. Apart from that fact it should also be noted that the results agreed very satisfactorily for radial displacements of the downstream face but were not so perfect for the rest. From results of model studies carried out in Portugal, the differences of tangential foundation displacements and the vertical ones appeared to be a direct consequence of the difference between Poisson's ratio for the model and that of the calculation.

Finally, Mr Serafim pointed out once again that, since the usual safety criteria were based on the values of stresses, in view of the high theoretical perfection of the calculation method presented the stresses determined by that method ought to be compared either with stresses determined by models or by observation of the prototype.

**Mr P. O. Wolf** (Lecturer in Fluid Mechanics and Hydraulic Engineering, Dept of Civil Engineering, Imperial College of Science and Technology) observed that he had had the privilege of being consulted by the Authors at various times during their investigations, particularly on questions arising out of practical problems of engineering design and construction, and he would comment on certain matters arising out of the application of the Authors' work to actual structures.

As had been mentioned before, the "relaxation" analysis and the model tests were concerned with idealized "mathematicians' dams" of uniform elasticity. The methods described in the Paper would enable the skilled designer to compare, to any desired degree of accuracy, the performance of such idealized arch dams of various proportions. Having found the most desirable shape of dam, the designer would then have to frame a specification, and the contractor would have to adopt construction methods, to ensure that the actual dam would in every way behave, as nearly as possible, like the idealized dam. That would require very careful control of concrete quality, temperatures, construction joints, grouting techniques, etc.

Even so, the material in the actual structure would never be perfectly elastic—a deviation from the idealized case which would more often than not result in an increase in the margin of safety—nor completely homogeneous or "of one piece".

With regard to the differences between the tensile and the compressive strengths of concrete, it was common design practice to disregard tensile stresses altogether. In well-constructed arch dams, however, the concrete might be assumed to carry tensile stresses up to 100 or 200, or even 300, lb/sq. in.; under greater loads the tensile stresses would, owing to cracking, fall to zero. The method of "relaxation" was particularly suitable for the analysis of problems in which the result of one step in the analysis itself (in the present case the stresses at a point) provided the boundary conditions for the next step. Although an analysis which allowed for the weakness of concrete in tension would no doubt be more difficult still than the method described in the Paper, Mr Wolf trusted that it could be done. Would it, in that more realistic case, be preferable, however, to do the whole computation in terms of the stresses throughout the structure, in order that the repeated conversion from displacements to stresses and back again might be avoided?

**Mr H. D. Morgan** (Partner, Sir William Halcrow and Partners, Consulting Engineers) had indicated during the discussion that he would deal further with the trial-load method

of analysis as applied to the design of an arch dam in Portugal. For various reasons, trial-load analyses of the dam had been made at times spread over a number of years, and the opportunity had been taken to refine the method of approach. In all cases, it had been considered that sufficient accuracy would be obtained by considering one cantilever in the centre of the dam as being representative of all cantilevers.

Originally, the analysis had been carried out by a graphical method suggested by Frederick Noetzli in 1921. In that method the deflected shape of the hypothetical cantilever was determined by a neat graphical construction and compared with the deflexion of the arches from a set of curves prepared by Ivan E. Houk.

The method had the drawback that any adjustment to the load distribution involved a complete recalculation of the cantilever deflexions, which had proved to be rather laborious, and the following approach had been developed to speed up the work.

Fig. 55 showed a simple cantilever with a single point load $P$. With the fixed end of the

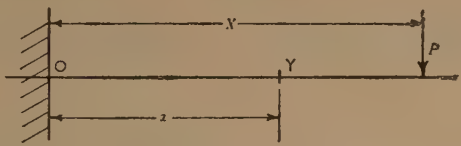


FIG. 55

cantilever as the origin of co-ordinates, the deflexion due to bending of any point such as $Y$ was given by:

$$\frac{P}{E}\int_0^{x_1}\int_0^{x_1}\frac{X}{I}-\frac{x}{I}\,dx\,.\,dx=\frac{P}{E}\,.\,X\int_0^{x_1}\int_0^{x_1}\frac{1}{I}\,dx\,.\,dx-\frac{P}{E}\int_0^{x_1}\int_0^{x_1}\frac{x}{I}\,dx\,.\,dx$$

The two double integrals were evaluated by assuming that the cantilever thicknesses varied linearly between the design points of the cross-section. However, the arithmetic became very cumbersome and as a check the integrals had also been evaluated by taking the values of $I$ at the intersections with the hypothetical arches and using the mean-ordinate method of integration. The latter method gave results not more than 5% greater than the more rigorous method and in very much less time. By organizing the work in tabular form, the mean ordinate calculations could conveniently be given to a comptometer operator, and the recalculations arising from a modification to a tentative design were reduced to the minimum.

For points beyond the load, deflexions were obtained by Clerk Maxwell's reciproca theorem, and, as a check, from the deflexion and slope at the load point. The slope under the load point was given by:

$$\frac{P}{E}\,.\,X\int_0^{x_1}\frac{1}{I}dx-\frac{P}{E}\int_0^{x_1}\frac{x}{I}\,dx$$

both of which integrals appeared in the calculation of the second integrals referred to previously.

Shear deflexions were obtained by a similar process but except at the bottom of the cantilever, their effect was negligible.

To consider distributed load, reference should be made to Fig. 56. The hypothetical arches were shown equally spaced as A, B, . . . F. The loading diagram was shown divided into a series of triangles, and to well within the accuracy necessary, the triangles could be resolved into point loads acting at A, B, . . . F, equal to the product of the intensity at those points and the arch spacing. Strictly, that did not hold at either end of the cantilever, but in practice the lower shaded triangle might be neglected altogether as having negligible effect on bending moments and deflexions, and the top triangle might be considered as acting at the top of the cantilever.

That division of the loading diagram had allowed the preparation of a Table showing the deflected form of the cantilever in terms of the intensity of cantilever loading at the level of each of the arches.

The solution of the problem had then turned on making the arch deflexions equal the cantilever deflexions. A guess had been made as to the load distribution, and a comparison had been made between the cantilever deflexions and arch deflexions as determined from Houk's curves. The magnitude and direction of the error had suggested where modifications could be made in the load distribution so as to reduce that error. Bearing in mind that the functions were linear it was only necessary to consider the deflexions due to the modification and add them to the previous answer. No great accuracy had been necessary in calculating the effect of those adjustments, speed rather than precision being the keynote. A careful note had been kept of the adjustments to the

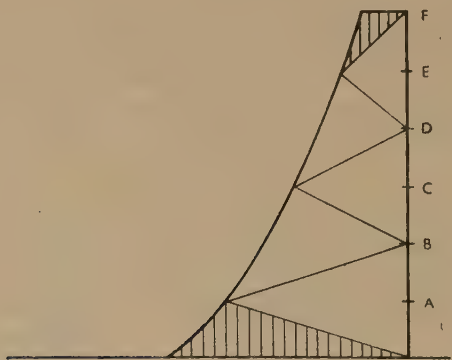


FIG. 56

load distribution so that when the errors had been reduced to a suitable extent, say 5% of total deflexion at any point, a check could be made by working out the deflexions resulting from the final load distribution.

The stresses in the cantilever had been found by normal methods and in the arches by reference to a chart due to Fowler which gave quite sufficient accuracy.

The elasticity of the abutments of the dam had an important effect on the stress distribution which could not be ignored; in general it tended to reduce the stresses that would result from perfectly rigid abutments. The great difficulty lay in obtaining reliable figures for the effective coefficient of elasticity of the rock, as the Authors had brought out in the Paper.

Various authors had analysed that problem at great length, but since there was liable to be a margin of uncertainty in the fundamental data of as much as 3 to 1, any great elaboration was inappropriate.

From figures given by Vogt and summarized by Davis, it would appear that the significant effects of abutment elasticity might be allowed for if the structure was considered as being rigidly founded at depth equal to its thickness below true foundation level when $E_r$ (rock) $= E_c$ (concrete); and otherwise inversely as $E_r$.

The Authors had rightly stressed the importance of temperature effects. The deflexions of free arches due to a uniform change in temperature had been estimated from Houk's curves and the resultant stresses from a set of curves based on Cain's analysis. The stresses in the hypothetical cantilevers of an arch dam, considered separately, were not changed by temperature variations. A new distribution of the hydrostatic loads had to

take place and a calculation had therefore to be made to give the cantilever stresses and the modification to the arch stresses resulting from cantilever action.

The actual temperature variations considered had been based on measurements taken deep inside dams in a similar climate. The temperature had been assumed uniform from the air face to the water face, no account being taken of temperature gradients within the structure because they were argued to give a generally favourable redistribution of stresses.

Account had been taken of the dilatation, or swelling, of the concrete due to soaking from the impounded water, and from the available data it had been apparent that the effect produced would be equivalent to an effective temperature rise of 10°C. That had been allowed for in determining the design-temperature range.

The methods which had been evolved from experience with the Alto Ceira dam were speedy in their application, which made them valuable for design purposes.

The time available for design was always limited and the designer had to consider alternative types of structure. Calculation should not be regarded as an end in itself, and with a lengthy computation procedure in the preliminary design there was always the dangerous tendency to regard results as being satisfactory provided that the maximum allowable stresses had not been exceeded, without asking whether material could in fact be saved.

The method outlined above was sufficiently simple to allow preliminary trial designs to be made and did not call for specialist techniques.

Mr Morgan was not derogating the work which the Authors had presented. A thorough investigation such as that made into the Dokan dam was clearly a very important final step in such a design, but such an approach could not be regarded as suitable for preliminary trials. Engineers in general could not maintain a department capable of undertaking such a task and it was appropriate and convenient for the Universities to provide that service.

Mr Morgan considered the Authors' investigation to be a great step forward in the evolution of arch-dam analysis. It was a matter for congratulation that it should come from a British source.

**The Authors**, before replying in detail to contributors to the discussion, drew attention to Paper No. 6155,[59] reference to which would indicate that some of the points raised had already been considered and at least partially dealt with.

Dr Zienkiewicz had given an interesting and welcome solution for the thin-shell tumbler. The general agreement of his results with those obtained from the fuller tumbler solution in the Paper was not altogether surprising, but neither could be more than preliminary assessments of the three-dimensional stress situation, and for the determination of that the vertical and tangential components of displacement were essential. Dr Zienkiewicz's statement that the thickness of the arch in his treatment was very small, was somewhat misleading: in neither tumbler solution could arch action, as distinct from hoop compression occur, and because of that an otherwise attractive method was of little value for the accurate calculation of stresses.

The Authors regretted that Dr Leliavsky did not consider the analysis more than an interesting attempt at a solution; in their view it did in fact provide the most complete mathematical solution yet obtained.

Dr Leliavsky was undoubtedly correct in his remark that a true solution based on the theory of elasticity would indicate infinite stresses at perfectly sharp re-entrant corners: that was not peculiar to the problem of the arch dam, but arose wherever such sharp corners occurred in a loaded structure. Dr Leliavsky's inference that a theoretical method which did not indicate stresses rising to infinity would be preferable was open to grave criticism for, if such a method disposed of those stresses by a theory which correctly portrayed the true situation, it could only do so by an arbitrary assumption which merely hid an awkward fact. The practising engineer might have doubts when given a solution which showed local infinite stresses at certain points but it could at least be said that the solution offered by the Authors did not dispose of his doubts by making use of unsubstantiated artifices.

Dr Leliavsky was under a misapprehension when he assumed that the Authors postulated the extent of the spread in the localized high stresses. Whether or not the Authors' statement that high stresses would be relieved by creep was accepted by designers, did Dr Leliavsky really doubt that it was an accurate statement of physical fact?

The stresses in Table 10 had been calculated making allowances for the fillets on the air-face, for the reason given on p. 223. Thermal stresses had been computed by relaxation for the tumbler problem only and not for the three-dimensional dam; the stresses at the abutments had been calculated (see Paper No. 6155, p. 272) by a conventional method, and only then had allowance been made for the effect of fillets, although they were of course represented in the model. Unless Dr Leliavsky's question as to the fundamental difference between the present approach and the usual methods was purely rhetorical it was difficult to understand, since he made it clear that relaxation solved the complete equations of elasticity for the solid dam: that differentiated it from all other methods in which assumptions, often of an extremely drastic character, were necessary to simplify or simulate elastic theory.

Dr Leliavsky raised an important question about allowable stresses, and that was touched upon in Paper No. 6155. That problem again was not peculiar to the arch dam but arose whenever a new method of calculation was formulated. All engineering stress analyses were necessarily approximate and acceptable methods had usually been achieved by a process of evolution. Most of them aimed at the computation of stresses due to specified loading and terms occurred having the correct dimensions of such quantities, although the numerical values assigned to them often had very little relation to fact. They were merely parameters in an equation to which certain empirical values were given to obtain results for comparison with similar calculations. If the basis of stress calculation was altered, the numerical values ascribed to those parameters had also to be altered, as Dr Leliavsky had pointed out, and almost invariably, as analysis became more refined, so could allowable stress values be increased. It was a common criticism that development of theory tended to make structures heavier. That was often true but arose not from any fault of the scientist but because the engineer was too often afraid to reduce the factor of ignorance to which he was accustomed in order to keep pace with more exact knowledge. The Authors therefore agreed with Dr Leliavsky that customary stress values were probably not applicable to the new method of calculation. When he asked, however, what stresses were allowable, the only possible answer was that at the moment there was not enough experience to say. It was, however, reasonable to expect that higher stresses would be permissible as stress analysis became more accurate. The only methods of resolving doubts about it were by the comparison of stresses from theoretical calculations with those measured in an actual structure; by a series of model experiments in which stresses could be accurately determined; or by computations made to compare the results of different methods of calculation when applied to the same structure. The measurement of stresses in an actual dam presented grave difficulties, and the results obtained were so open to criticism that, apart from other considerations, it was not a very useful approach. The other two methods, in which conditions could be accurately controlled, should certainly be studied. The Authors were continuing their investigations so far as possible with the limited resources in funds and staff at their disposal, but some time would elapse before results could be expected.

Dr Leliavsky's remarks about the Juillard movements were interesting, but it was difficult to see how any theoretical treatment could allow for them.

Professor Berio, taking the opposite point of view from Dr Zienkiewicz, was pleased that the Authors had rejected current hypotheses which assimilated an arch dam to a thin shell. Whilst Dr Zienkiewicz's treatment was of a new type, it was undoubtedly true that many of the methods proposed, and indeed successfully used, for the design of arch dams had made the assumption, either explicitly or implicitly, that the structure was of that simplified type. The Authors agreed with Professor Berio that the results of the Dokan research should be used to check simplified methods and hoped that Paper No. 6155 would give him at least something of what he wanted. They had every sympathy with his suggestions

or future work but, as already indicated in reply to Dr Leliavsky, it was almost entirely matter of time and money.

The problem raised by the difference in Poisson's ratio as between model and prototype was, as the Authors had always realized, one of fundamental importance and since the presentation of the Paper a model had been made in Sorboprene, for which Poisson's ratio was practically zero, to the same drawings as the first pilot model Fig. 7 (facing p. 208). Owing to limitations in the sizes of material available, it had had to be made to four-fifths of the scale of the rubber pilot model. It had been loaded similarly, the water being contained in a polythene bag. The radial displacements on the centre section had been measured as before, and, after correction for scale and Young's modulus, had been plotted with those for the rubber model for which Poisson's ratio was 0·5. The comparison was shown in Fig. 57, and in spite of some discrepancies the agreement between the two sets of

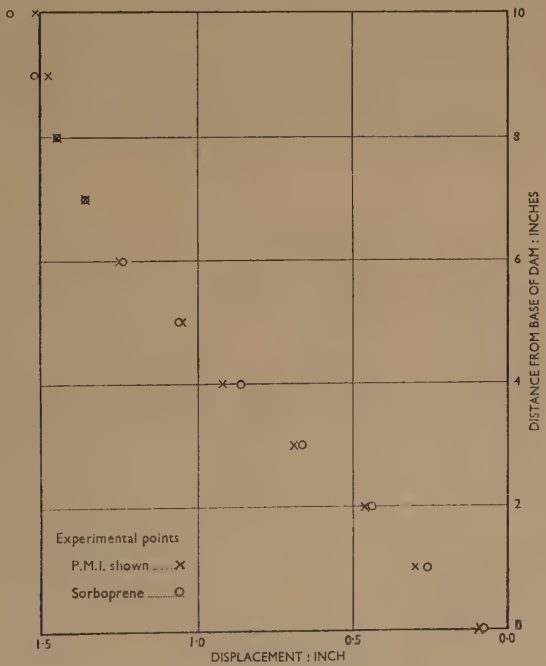


Fig. 57.—Deflexion of centre section caused by water pressure

points was remarkable. Unfortunately, Sorboprene did not show a good linear variation between displacements and loads, and a mean value of Young's modulus of 20 lb/sq. in. had been adopted. It was evident that on the centre section of a symmetrical dam at least, the widest possible variation in Poisson's ratio made very little difference to the shape of the curve of radial displacements, and that confirmed certain views expressed by Mr Serafim to which reference would be made later. The Authors were grateful to Professor Berio for his extremely useful list of reports on Italian tests, and agreed with him as to the need for obtaining as much information as possible, both practical and theoretical, in such an important field of engineering structures.

Professor A. L. L. Baker's contribution, as a result of his experience with other structures, was based on the same fundamental idea as the trial-load method, and he had

given an interesting graphical method of obtaining a solution of the equations involved. The Authors could not say, without experience, whether it would be helpful in the problem of the arch dam, and a fairly complete investigation of such a structure would be necessary to determine that.

Mr Snell had commented on the size of the mesh used in the relaxation calculations. The dimensions quoted on p. 204 had been used in the three-dimensional solution, and a mesh smaller by one-half for the tumbler solution. With regard to the results of photo-elastic tests mentioned by Mr Snell, the Authors would expect a considerable increase in the vertical stress component in a two-dimensional as compared with that found in a three-dimensional solution. Reference to Dr Hoyle's original enunciation of the thermal equations which had led to the work at Imperial College would be found on p. 258.

In reply to Mr Veltrop, the same value of Young's modulus had been taken for concrete and rock, since site measurements showed that to be approximately true; the variations among results had been such that no significance could have been attached to calculations which attempted to allow for them. It was, however, quite feasible to allow for any such variations in the relaxation calculations; the work would naturally be increased, but not unduly. Again, the arithmetic would be heavier if the arches were of varying thickness, but a large increase in the number of space lattices, as contemplated by Mr Veltrop, could be avoided by using a graded lattice having different dimensions in different regions. Mr Veltrop would be interested to learn that a great deal of the more tedious arithmetic could now be avoided by electronic computers, so rapidly had those machines developed, and those responsible for the relaxation calculation would not be alarmed by the introduction of the extra complexities of detail suggested by Mr Veltrop. On the other hand, they could see no method by which relaxation could allow for cracks in the structure, and it would seem that that could only be done empirically in any design method. Mr Veltrop's comments on the reliability of the stresses provided by the tumbler solution had been fully appreciated throughout the investigation; both that solution and the model measurements had been of great use in making the initial estimates of the three-dimensional displacements. The model had indicated that the variation of those displacements round an arch was very nearly sinusoidal, whilst the tumbler solution provided a distribution of the radial and the vertical displacements through a vertical section of the dam; the two results had been combined in the initial guess for the three-dimensional solution. An analysis of another structure broadly similar to Dokan would show a 50% saving in time at least, and a tumbler solution could be found in about one man-month by an experienced operator in relaxation technique. It was estimated that a complete three-dimensional solution should not take more than from 9–12 man-months.

In view of Mr Serafim's interesting and authoritative remarks on the use of models, the Authors hoped that he might be interested in Paper No. 6155. They agreed with his view that the stresses at the centre were probably not much affected by differences in Poisson's ratio, and the results of a simple test on Sorboprene shown in Fig. 57 afforded some confirmation of that. They also believed that there was justice in his remarks about the abutment stresses, but unfortunately could not at the moment give any direct information about it; investigations were, however, now in hand, both by calculation and experiment, which it was hoped would throw some light on it. They thanked Mr Serafim for his information as to the previous use of the two methods suggested for determining the gravity stresses experimentally. It was not surprising that both of them were arrived at independently in different laboratories. Mr Serafim, as well as Mr Snell, had commented on the lack of precision allowed in the assessment of thermal stresses; the Authors agreed with the comment but were of the opinion that an inherent lack of knowledge of temperature conditions throughout the dam prevented a more positive assessment. They derived considerable satisfaction from Mr Serafim's remarks that the temperature variations actually considered were too severe and would never occur. They believed that to be correct, particularly since certain additional factors, such as the expansion of saturated concrete, had not been considered. They had no doubt that their assumptions had been very severe.

The Authors would express their appreciation to Mr Wolf for the help which he had given them in connexion with a number of points which had arisen during the investigation, and in reply to his question, regretted that they could see no hope of solving any three-dimensional stress problem by computation directly in terms of the stresses induced.

The Authors thanked Mr Morgan for contributing an account of the shortened form of trial-load analysis which had been used during the early stages of design of a recently constructed dam. They agreed with him that it was essential that the designer should be provided with means of making a quick assessment of the effects of alterations in the early stages, and for that purpose design Tables were a great convenience. One of the difficulties in a structure as complicated as an arch dam was that the use of too rough an approximate method for determining the vertical stresses might, in the end, lead to considerable waste of material owing to the large factor of ignorance with which they would have to be associated.

In conclusion, reference might be made once more to the future work now in hand. Further rubber models of dams in idealized valleys and with positively defined boundary conditions were nearing completion. Three research workers would be engaged in the study of those models and, in addition, it was hoped that relaxation calculations would be made for all of them for comparison with approximate methods which had been used or suggested for preliminary design purposes. That work would be done as soon as possible, but some time must necessarily elapse before results could be reported.

## Further references


28. S. Timoshenko, "Theory of Plates and Shells". McGraw-Hill, New York, 1940. See p. 390.
29. S. Leliavsky, "Sazillism: Its Origin and Evolution". *Engineer*, vol. 183, p. 374 (2 May, 1947).
30. Sir J. W. Ottley and A. W. Brightmore, "Experimental Investigations of the Stresses in Masonry Dams subjected to Water-Pressure". Min. Proc. Instn Civ. Engrs, vol. 172, p. 89 (1907–8, Pt II). See p. 103.
31. L. F. Richardson, "The Approximate Arithmetical Solution by Finite Differences of Physical Problems involving Differential Equations, with an Application to the Stresses in a Masonry Dam". Phil. Trans Roy. Soc. Lond., Series A, vol. 210, p. 307.
32. J. H. A. Brahtz, "The Stress Function and Photo-Elasticity Applied to Dams." Trans Amer. Soc. Civ. Engrs, vol. 101 (1936), p. 1240.
33. Karl Pearson and A. F. Campbell Pollard, "An Experimental Study of the Stresses in Masonry Dams." Drapers' Co. Res. Memoirs, Dulau, London, 1907. See Fig. 2.
34. Prof. Kurt Beyer, "*Die Statik im Eisenbetonbau*" ("Statics in Reinforced Concrete Construction"). Springer, Berlin, 1934, vol. 2, p. 743 *et seq.*
35. W. S. Gray, "Reinforced Concrete Reservoirs and Tanks." *Concrete Pubs*, London, 1942, p. 11 *et seq.*
36. G. A. Hool and N. C. Johnson, "Concrete Engineers' Handbook; data for the design and construction of plain and reinforced concrete structures." McGraw-Hill, New York, 1919. See p. 765.
37. A. E. Komendant, "Economy and Safety of Different Types of Concrete Dams." Proc. Amer. Soc. Civ. Engrs, Separate No. 684, May 1955.
38. J. Lombardi, "*Les Barrages en Voute Mince*" ("Thin-arch dams"). Rouge, Lausanne, 1955.
39. A. Ludin, "*Wasserkraftanlagen*" ("Hydro-power plants"). Springer, Berlin, 1938. See 2nd half, 1st part—F. Toelke, "*Talsperren*" ("Dams").
40. H. Ritter, "*Berechnung der bogenförmigen Staumauern*" ("Arch-dam calculation"). Karlsruhe, 1913.

41. A. Berio, "*Sulla verifica delle dighe ad arco ed arco-gravita mediante estensione della teoria dei serbatoi*" (Relating to the tests of arch dams and gravity-arch dams by means of extension of the theory of reservoirs"). *Energia Elettrica*, 1950.
42. M. Bernardi, "*Raffronto tra i risultati sperimentali su modello ed i calcoli istituiti secondo il metodo del Toelke per una grande diga ad arco*" ("Comparison between the results obtained from experiments on models and the calculations established by the method of Toelke for a large arch dam"). *Symposium de Constructions Hydrauliques*, Rome, 1954.
43. M. Bernardi, "*Sul calcolo di prima approssimazione delle dighe ad arco-cupola*" ("On the first approximate calculations relating to cupola-arch dams"). In preparation.
44. G. Oberti, "*Ricerche sperimentali sul comportamento statico delle dighe*" ("Experimental research on the static behaviour of dams"). *Elettrotecnica*, 1949.
45. G. Oberti, "*La ricerca sperimentale su modelli come contributo al progetto delle grandi construzioni*" ("Experimental research on models as a contribution to the plan for large constructions"). *Tecnica Italiana*, 1951.
46. E. Torroja, "*Etudes sur des modèles réduites de structures réalisées dans le Laboratoire Central de Matériaux à Madrid*" ("Studies on scale models of structures carried out in the Central Laboratory of Materials at Madrid"). Symposium on "Models in Technical Investigation", Venice, 1955.
47. M. Rocha, "The studies of structures by models in Portugal." Symposium on "Models in Technical Investigation," Venice, 1955.
48. G. Oberti, "*Risultati di studi sperimentali sopra un modello di diga ad arco recentemente construita*" ("Results of experimental studies on a model of an arch dam of recent construction"). *Energia Elettrica*, 1948.
49. G. Oberti, "*Diga del Lumiei—Criteri di progetto e studi sperimentali*" ("Dam of the Lumiei—Details of the project and experimental studies"). *Energia Elettrica*, 1948.
50. A. Berio, "*Alcuni risultati sperimentali ricavati da un modello di diga da arco*" ("Some experimental results obtained from a model of an arch dam"). *Energia Elettrica*, 1953.
51. G. Grandori, "*Risultati di esperienze eseguite su un modello di diga a volta*" ("Results of experiments carried out on a model of an arch dam"). *Energia Elettrica*, 1954.
52. A. Danusso and G. Oberti, "*Diga arco-gravità sul Piave—Criteri di progetto e ricerche sperimentali*" ("Gravity-arch dam on the Piave—Details of the project and experimental research"). *Energia Elettrica*, 1955.
53. R. D. Hoyle and E. James, "Axially Symmetrical Thermal Stress Problems." Aircraft Engng, vol. 26, 1954, p. 53.
54. A. L. Parme, "Arch Dams with Arches of Variable Thickness." Modern Developments in Reinforced Concrete, No. 21, 1948. Portland Cement Assocn, Chicago.
55. M. Rocha and J. Laginha Serafim, "Analysis of Arch Dams by Model Tests." Fifth Congress on Large Dams, Paris, 1955.
56. M. Rocha, J. Laginha Serafim, A. F. da Silveira, and J. M. R. Neto, "Model tests, analytical computation and observation of an arch dam." Proc. Amer. Soc. Civ. Engrs, Separate No. 696, May 1955.
57. G. E. Beggs, "Arch Dam Investigation," vol. 3, p. 150. The Engng Foundation, New York, 1933.
58. M. Rocha and J. Laginha Serafim, "Model tests of Santa Luzia Dam." Third Congress on Large Dams, Stockholm, 1948.
59. Letitia Chitty and A. J. S. Pippard, "The determination of the stresses in an arch dam from a rubber model." Proc. Instn Civ. Engrs, Part I, vol. 5, p. 259 (May 1956).

## Erratum

Proceedings, Part I, May 1956, p. 241, footnote: for "p. 230" read "p. 258."

## ELECTION OF ASSOCIATE MEMBERS

The Council at their meeting on 15 May, 1956, in accordance with By-law 14, declared that the following had been duly elected as Associate Members:

Angwin, John Osborne, B.Sc.(Eng.) (*London*), Grad.I.C.E.
Candish, Allan Alfred.
Downey, Victor Michael, Grad.I.C.E.
Ellen, Peter Edington, B.E. (*New Zealand*).
Fernando, Merennege Ratnaphala, B.Sc.(Eng.) (*London*), Grad.I.C.E.
Geach, Trevor Trenley Ward, Grad. I.C.E.
Henderson, Francis Martin, B.E. (*New Zealand*).
Hooper, Ian Ross, B.A. (*Cantab.*), Grad. I.C.E.
Hutt, Edward Alexander, B.Sc. (*New Zealand*).
James, Dennis Frederick, Grad.I.C.E.
Macky, Robert Graham, B.E. (*New Zealand*), Grad.I.C.E.
Mahalingam, Sivapragasam, Grad.I.C.E.
Mead, Ronald James, B.Sc.(Eng.) (*London*), Grad.I.C.E.
Pathmanathan, Sabharatnam, B.Sc. (Eng.) (*London*), Grad.I.C.E.
Powell, Philip John.
Russell, Hamish Fleming, B.Sc. (*Glasgow*), Grad.I.C.E.
Saunders, Reginald Edward Knox, B.Sc. (*Witwatersrand*).
Skepper, Herbert Gordon, B.Sc.Tech. (*Manchester*).
Wilson, Brian Harold, B.A. (*Cantab.*), Grad.I.C.E.
Wyatt, William Ronald Macdonald, B.Sc. (*Glasgow*), Grad.I.C.E.

## DEATHS

It is with deep regret that intimation of the deaths of the following has been received.

### *Members*

John Edward Bostock, O.B.E. (E. 1904, T. 1916).
Herbert Walter FitzSimons, B.Sc.(Eng.) (E. 1905, T. 1923).
James Percy Hallam (E. 1942).
Frank Walton Jameson (E. 1924).
Arthur Ernest Jennens, B.Sc. (E. 1923, T. 1951).
William Lowe Lowe-Brown, D.Eng., M.Sc. (E. 1902, T. 1910).
James MacAlister (E. 1913, T. 1924).
William Allan Macartney (E. 1910, T. 1936).
Robert Stribley Murt, O.B.E. (E. 1920, T. 1932).
Harold Lashmar Penfold, M.A. (E. 1915, T. 1926).
Robert William Roy Rankin, M.A., M.A.I. (E. 1922, T. 1946).

### *Associate Members*

Arthur Banks (E. 1915).
George Samuel Elam Barker (E. 1924).
Robert Blackburn, O.B.E. (E. 1913).
Stanley Coles, B.Sc.(Eng.) (E. 1911).
Edward Henry Harrison (E. 1889).
Francis Percy Kindell, D.S.O., M.C. (E. 1912).
Ernest Arthur McGill, O.B.E., M.Sc. (E. 1919).
Hugh John Melliss, B.A. (E. 1905).
James Moore (E. 1906).
John William Price (E. 1923).
Henry Ernest Robarts (E. 1906).
Thomas Rooke (E. 1899).
Cyril Walmesley (E. 1915).

# REPORT OF THE COUNCIL AND STATEMENT OF ACCOUNTS 1955–56

1. In accordance with the By-laws, the Council present the following report on the state of the Institution.

2. **Meetings.**—Eight Ordinary, five Joint, two Supplementary, twenty-eight Divisional Meetings and one Special General Meeting have been held, a total of forty-four as compared with thirty-five in Session 1954–55. Of the five Joint Meetings two were held with the Institution of Mechanical Engineers, one with the Institution of Electrical Engineers, and two Joint Meetings of the three Institutions were held at the Institution of Mechanical Engineers.

3. A list of the Papers and Lectures presented at the Meetings will be found in Appendix I.

4. The Opening Meeting of Session 1955–56 took place on the 1st November when Mr W. K. Wallace in his Presidential Address first described the construction of the London and Birmingham Railway by Robert Stephenson and later in his Address paid a tribute to the skill and ability displayed in the design of the Britannia Bridge by Stephenson when he was Engineer of the Chester and Holyhead Railway.

5. **Special General Meeting.**—A Special General Meeting was held on the 16th January, 1956, with Mr W. K. Wallace, President, in the chair. The meeting, which was attended by over 350 Corporate Members, had been requisitioned under the By-laws by twenty-four Corporate Members calling upon the Council to abolish election direct to full membership. The Council gave notice of an Amendment recommending the re-examination of the By-laws governing direct election. Twenty-two speakers took part in the discussion and the amendment was carried by a majority of 187 to 41.

6. **Awards for Papers.**—The list of awards will be found in Appendix II for Papers presented at Ordinary and Divisional Meetings in Session 1954–55, for Papers printed in the Proceedings with written discussion only between January and December 1954, and those to Graduates and Students.

7. **Conferences.**—*Conference on the correlation between calculated and observed stresses and displacements in structures.*—This Conference was held at the Institution on 21 and 22 September, 1955, the attendance being 272.

8. The following is a list of the Papers presented for discussion:—

"Some factors in the field testing of structures," by F. G. Thomas, Ph.D., B.Sc., M.I.C.E.

"Site strain measurements: some philosophical aspects," by A. Goldstein, B.Sc. (Eng.), A.M.I.C.E.

"Techniques for field measurements of deformation and earth pressure," by W. H. Ward, B.Sc.(Eng.), A.M.I.C.E.

"Testing of prestressed steelwork," by R. A. Sefton Jenkins, B.Sc.(Eng.), A.M.I.C.E.

"Loading tests on bridges," by F. G. Thomas, Ph.D., B.Sc., M.I.C.E.

"Stress measurements in the steel frame of the new Government Offices, Whitehall Gardens," by R. H. Wood, B.Sc., Ph.D., A.M.I.C.E., A.M.I.Mech.E., and R. J. Mainstone, M.Eng.

"The behaviour of saw-tooth portal frames," by Professor J. F. Baker, O.B.E., M.A., Sc.D., D.Sc., M.I.C.E., and K. G. Eickhoff, M.A., A.M.I.C.E.

"Some experiments on Clifton Suspension Bridge," by A. R. Flint, B.Sc., Ph.D., and Professor A. G. Pugsley, O.B.E., D.Sc.(Eng.), M.I.C.E., F.R.S.

"Tests to destruction on a Vierendeel girder," by Professor F. B. Bull, M.A., B.Sc., B.E.

"Full-scale loading tests on a welded plate-girder floor system," by B. E. S. Ranger, A.M.I.C.E., and Jacques Heyman, M.A., Ph.D., A.M.I.C.E.

"The design of a raw-sugar silo," by E. T. Moss, Ph.D.

"Telephone Manager's Office, Kilburn," by H. C. Adams, B.Sc., S. C. C. Bate, B.Sc., A.M.I.C.E., and F. Walley, M.Sc., A.M.I.C.E.

"Site strain measurements: examples of prestressed concrete structures," by A. Goldstein, B.Sc.(Eng.), A.M.I.C.E.

"Loading tests on the floor systems of a reinforced concrete building," by A. J. Ockleston, B.E., Ph.D., D.Sc.(Eng.), M.I.C.E.

"Load tests on a small prestressed-concrete highway bridge," by P. B. Morice, B.Sc., Ph.D., Grad.I.C.E., and G. Little, M.Sc.

"The deflexion of reinforced concrete portal frames with sloping rafters," by W. C. Andrews, O.B.E., M.I.C.E., and E. F. Whitlam, M.Sc.(Eng.), A.M.I.C.E.

"Test of a precast prestressed shell roof," by J. J. Lewkowicz, Dipl. Ing., A.M.I.C.E.

"Settlement studies on structures in England," by L. F. Cooling, D.Sc., and R. E. Gibson, Ph.D., A.M.I.C.E.

"A survey of comparisons between calculated and observed settlements of structures on clay," by D. H. MacDonald, Ph.D., and Professor A. W. Skempton, D.Sc.(Eng.), A.M.I.C.E.

"Some comparisons between measured and calculated earth pressures," by W. H. Ward, B.Sc.(Eng.), A.M.I.C.E.

9. *Conference of the Representatives of the Engineering Societies of Western Europe and the United States of America (EUSEC).*—The fourth conference was held in Copenhagen from 5 to 9 September, 1955. The Institution was represented by the President, Mr David M. Watson, and the Secretary. Some 18 Resolutions and Recommendations were adopted.

10. **Publications**.—The circulation figures for the "running" publications are:—

*Proceedings*

| | | | | | |
|---|---|---|---|---|---|
| Part | I, | published | 6 times a year | — 22,300 | copies of each number |
| ,, | II, | ,, | 3 ,, ,, | — 7,600 | ,, ,, ,, ,, |
| ,, | III, | ,, | 3 ,, ,, | — 8,600 | ,, ,, ,, ,, |

*Chartered Civil Engineer*, issued 6 times a year—21,800 copies of each number.

*Géotechnique*, issued 4 times a year—1,800 copies of each number.

11. The following have been published during the year:—

Proceedings of the Conference on the Correlation between Calculated and Observed Stresses and Displacements in Structures.—Preliminary volume.

"The Aesthetic Aspect of Civil Engineering Design" (reprinted).
"The siting and design of harbours," by E. J. Buckton, B.Sc.(Eng.), M.I.C.E. (Vernon Harcourt Lecture, 1954–55).
Combined subject and name index to all Institution publications from Nov. 1948 to Dec. 1954.
Supplement to the Bibliography on Soil Mechanics covering the year 1954.
Christmas Cards for sale to members, 1,232 doz. of which were purchased.

12. **Engineering Divisions.**—The number of meetings and the number of visits to works of engineering interest arranged by the Divisions were as follows:—

| *Division* | *Meetings* | *Visits* |
|---|---|---|
| Airport | 2 | 2 |
| Hydraulics | 3 | 1 |
| Maritime and Waterways | 3 | 2 |
| Public Health | 4 | 2 |
| Railway | 4 | 1 |
| Road | 3 | 2 |
| Structural and Building | 5 | 2 |
| Works Construction | 4 | 0 |
| | 28 | 12 |

13. One of the Railway Division Meetings took the form of an Informal Discussion. One of the Hydraulics Division Meetings was followed by a Joint Meeting with the Institution of Mechanical Engineers, and one of the Public Health Division Meetings was included in the Programme of the British Nuclear Energy Conference. The titles of the Papers and the names of the Authors will be found in Appendix I.

14. **Library.**—During the year 564 volumes were presented to the Library and 459 were purchased making a total on the 31st March of 70,740 volumes and 18,984 pamphlets.

5,142 applications for the loan of books were dealt with.

15. **Local Associations.**—During the year the Local Associations have continued their activities; brief accounts of these appear in Appendix III.

Following the Council's decision that each of the Vice-Presidents should, if practicable, visit two Local Associations each year, the following visits were made:—

| | |
|---|---|
| Mr Gourley | Northern Ireland Association (Belfast) |
| Sir Arthur Whitaker | Edinburgh and East of Scotland Association (Perth) |
| | Southern Association (Chichester) |
| Professor Pippard | South Wales and Monmouthshire Association (Cardiff) |
| | Midlands Association (Birmingham) |

16. Awards made by the Council for Graduates' and Students' Papers presented before Local Associations in Session 1954–55 included Miller Prizes to two Graduate members of the Glasgow and West of Scotland Association, to one Graduate member of the North-Western Association, and to a Student member in each of the Midlands, Edinburgh and East of Scotland, and South-Western Associations.

17. The Dugald Clerk Lecture "Some factors in the design and construction of oil refineries," by H. J. W. Braddick, was repeated before the Northern Counties, Northern Ireland, and Southern Associations.

18. **Overseas Associations.**—Under the Chairmanship of Mr W. S. Stredwick, M.I.C.E., who succeeded Mr D. I. Todman, M.I.C.E., the 27 years old Malayan Association, with the consent of the Council of the Institution, continued as a separate entity side-by-side with the Joint Oversea Group whose activities had been extended to include the Federation of Malaya. Mr K. G. Sehested, A.M.I.C.E., succeeded Mr L. D. Smith, B.Sc., Grad.I.C.E., as Hon. Secretary, Mr J. H. C. Shakespear, A.M.I.C.E., continued as Hon. Treasurer and Mr D. J. Fitz-Gibbon continued as Hon. Editor. The membership totalled 144 at the end of February 1956. A successful Annual Dinner was held at Kuala Lumpur in November 1955 at which the Minister for Works, Hon. Inche Sardon Bin Haji Jubir was the principal guest. Technical visits were arranged, some in collaboration with the Joint Group, and were well attended. The Association participated in the planning of the training of engineers at the Technical College, Kuala Lumpur. Mr G. M. Wheat, M.I.C.E., served on the Council of the Institution.

19. The Victorian Association continued its activities under the Chairmanship of Mr L. B. Mercer, M.C.E., M.I.C.E., and Mr F. W. Green, B.Sc., A.M.I.C.E., continued to act as Honorary Secretary. Mr T. M. Carey, M.I.C.E., was appointed Consultative Member in the vacancy caused by death in May 1955 of Dr W. D. Chapman, M.C.E., M.I.C.E. Three meetings were held in Melbourne, including a social evening with films. In addition Mr and Mrs Mercer entertained, at Adelaide, members of the Association.

20. Mr D. D. Ash, M.I.C.E., has been the Chairman of the Trinidad Branch of the West Indies Association and Mr C. Dupenois, B.Sc., A.M.I.C.E., succeeded Mr D. Watson, A.M.I.C.E., as Hon. Secretary. Following consultations with the members of the three Institutions in Trinidad it is hoped to set up a Joint Overseas Group. Meetings have been held throughout the year with the Institutions of Mechanical and Electrical Engineers, and members were invited to lectures given by the Architects Association and the Building and Allied Trades Association. The joint programme included a visit to the Port of Spain Power Station, the Trinidad Cement Works and lectures and film shows. The Joint Annual Dinner was held in January 1956 at the Queen's Park Hotel, Port of Spain. The principal guest was the Governor, Sir Edward Beetham, G.C.M.G., C.V.O., O.B.E., who was accompanied by Lady Beetham. It was the responsibility of the Branch to arrange the Annual Dinner which was presided over by the Chairman, Mr D. D. Ash.

21. A Joint Committee representing the Institution, the Toronto Branch of the Engineering Institute of Canada and the American Society of Civil Engineers, was set up to sponsor meetings of common interest in the Toronto area. The inaugural meeting was held in November 1955, and a further programme arranged. The Joint Committee has been under the Chairmanship of Mr H. Fealdman, M.A., A.M.I.C.E., P.Eng., M.E.I.C., and Mr B. Hardcastle, B.Sc., P.Eng., M.E.I.C., has acted as Honorary Secretary.

22. **Joint Oversea Groups.**—These Groups have continued their functions with vigour and enthusiasm.

23. After a period of comparative inactivity the Committee of the Argentine Joint Oversea Group have resumed meetings. The membership declined somewhat over the last few years but now stands at 118 of which 30 are members of the Institution.

At an Annual General Meeting held in December 1955, in Buenos Aires, Mr R. M. Drysdale, A.M.I.Mech.E., was elected Chairman, Mr C. Mellor, A.M.I.C.E., Vice-Chairman, and Mr J. Combes, B.Sc.(Eng.), A.M.I.C.E., Honorary Secretary and Treasurer.

24. In Hong Kong Mr A. W. Black, M.I.Mech.E., succeeded Mr S. E. Faber, A.F.C., B.Sc., M.I.C.E., as Chairman of the Joint Overseas Group and Mr F. E. Short, A.M.I.C.E., acted as Honorary Secretary during the absence on leave of Mr J. J. Robson, A.M.I.C.E. In collaboration with the Hong Kong Engineering Society numerous Papers were read and visits to engineering works arranged.

25. Mr N. D. Fetto, M.I.C.E., succeeded Mr R. C. Kelt, O.B.E., M.I.C.E., as Chairman of the Iraq and Persian Gulf Joint Oversea Group Committee and Mrs B. Shearman, A.M.I.E.E., acted as Honorary Secretary. The programme included meetings in Baghdad, when the Chairman gave his address which was followed by a talk by Mrs Shearman on the use of films in training; and in Kuwait when a Paper by Mr G. Walker, M.I.Mech.E., A.M.I.E.E., was discussed. Visits included one to the new South Gate Bridge in Baghdad.

26. During the year the Councils of the three Institutions approved the extension of the activities of the Singapore/Malayan Joint Oversea Group to cover the Federation of Malaya. The Group continued its activities under the Chairmanship of Mr W. G. Scott, M.I.E.E., and Mr Ng Wah Hing, M.A., Ph.D., A.M.I.C.E., continued to act as Honorary Secretary. Meetings included a film show and talk by Mr H. F. Goldstein, A.M.I.C.E., lectures by Mr J. Dyson, B.Sc.(Eng.), A.M.I.E.E., Mr R. M. Charley, M.C., B.Sc., M.I.E.E., and a talk by Mr M. C. Culley on air conditioning. Several visits were organized and were well attended. They included the Kallang Bridge; the Murnane Reservoir; the International Airport at Paya Lebar; Port Swettenham; and H.M. Naval Base.

27. The West African Joint Group, under the Chairmanship of Mr J. Houston Angus, M.I.E.E., organized a very full programme of meetings. Mr R. G. M. Bathgate, B.Sc., A.M.I.C.E., continued to act as Honorary Secretary of the Group and Mr D. F. Orchard, Ph.D., A.M.I.C.E., succeeded Mr I. Small, B.Sc., A.M.I.C.E., as Honorary Secretary of the Gold Coast Branch. Mr Bathgate has recently been succeeded by Mr R. E. J. White, A.M.I.Mech.E. Meetings included the discussion of the following Papers:—"Planning and engineering," by J. W. Henderson, E.R.D., B.Sc., M.I.C.E., "Choice of generating plant in Nigeria," by K. H. Widgery, B.Sc., A.M.I.E.E., "Petroleum fuels," by D. S. Longbottom, B.Sc., A.M.I.Mech.E., "Preservation of timber," by H. T. Astley, B.Sc., A.M.I.C.E. In addition the following papers were discussed at meetings of the Gold Coast Branch:—"The development of the diesel engine," by G. W. Glanister, "Achiasi Kotuk railway link," by A. A. G. Mackintosh, B.Sc., A.M.I.C.E., "Volta Bridge," by T. B. Bingham, B.Sc., A.M.I.C.E., and W. J. Harper. Visits included Ijora "B" Power Station, Lagos, Lagos Airport and the Lagos workshops of the West African Airways Corporation. The Gold Coast Branch visited the new Tema Harbour near Accra. A very successful Conversazione was held in Lagos in June 1955. Members and their guests were received by Col. and Mrs E. H. W. Biggs and Mr R. Bridgman. During July the Committee prepared, at the request of the Council of Ministers, comments on the report of the "Economic Developments of Nigeria," by a Mission from the International Bank which visited Nigeria in 1953. The Annual Dinner took place in February 1956.

28. **The Association of London Graduates and Students.**—The Opening Meeting was held on the 2nd November, when the Chairman of the Association, Mr P. J. Watson, B.Sc.(Eng.), Grad.I.C.E., gave an Address on "London's Water Supply," the President taking the Chair. The Dugald Clerk Lecture 1956, on "Some factors in the design and construction of an oil refinery," was delivered by Mr H. J. W. Braddick, B.Sc.(Eng.), A.M.I.C.E., on the 4th January. Two meetings were held for the reading and discussion of Graduates' and Students' Papers and two meetings were held at which informal addresses were delivered on "Some practical considerations concerning design of steel bridges," by Mr K. E. Hyatt, B.Sc.(Eng.), M.I.C.E., and "Site investigations," by Mr H. Q. Golder, D.Eng., M.I.C.E. A Joint Meeting with the Graduate and Student sections of the Institution of Mechanical Engineers and the Institution of Electrical Engineers took place on the 12th March, when General Sir Brian Robertson, Bt., G.C.B., G.B.E., K.C.M.G., K.C.V.O., D.S.O., M.C., gave a talk on "Railway modernization."

29. Seven visits to works of engineering interest were arranged during the Session. Social events included two Smoking Concerts, following meetings, and a joint dance with the Graduate and Student Sections of the Institution of Mechanical Engineers and the Institution of Electrical Engineers. In the Young Trophy sporting events the Institution was placed second, losing first place by one point only out of a total of 60 points.

30. **Competition for the Institution Medal and Premium (London University).**—The Ninth Competition for the Institution Medal and Premium (London University) was held at the Institution on Wednesday, 25 May, 1955. The President (Mr David M. Watson) was in the Chair, and the following Papers were presented in competition:—

"The design and construction of permanent-way," by V. S. Clemow, Stud.I.C.E. (King's College).

"Some properties of "no-fines" concrete and its future as a heavy structural component," by A. Hartley, Stud.I.C.E. (City and Guilds College).

Mr A. C. Hartley, Mr P. St. L. Lloyd, and Mr T. A. L. Paton acted as Judges and, on their recommendation, the Institution Medal and Premium of £10 were awarded to Mr V. S. Clemow. The Judges gave a commendable mention to Mr A. Hartley and awarded him a Premium of £5.

31. **Competition for the Institution Medal and Premium (Local Associations).**—This competition was held at the Institution on Thursday, 20 October, 1955, with the President (Mr David M. Watson) in the Chair, when the following Papers were ably presented:—

"The failure and repair of a steel sheet-pile dock wall," by R. J. Livesey, Grad.I.C.E. (Glasgow and West of Scotland Association).

"Uplift pressures in concrete dams," by James Park, B.Sc., Stud.I.C.E. (Edinburgh and East of Scotland Association).

"Some aspects of airport development," by J. L. Kay, B.Sc.Tech., Stud.I.C.E. (North-Western Association).

The Judges, Mr A. C. Hartley, Mr A. S. Quartermaine, and Mr H. Shirley Smith awarded the medal and Premium of £10 to Mr R. J. Livesey. The Judges gave a commendable mention to Mr James Park and awarded him a Premium of £5.

32. **Examinations.**—The number of Institution candidates who attended the Common Preliminary Examination of the Engineering Joint Examination Board was 82 for the October 1955 Examination, of whom 19 passed, 44 failed and 18 were referred. There were 106 entries for the April 1956 examination.

33. The number of candidates examined for the October 1955 Institution Examination (Parts I and II) was 430, including 88 at 23 centres overseas of whom 187 passed, 184 failed and 59 were referred. For the April 1956 Examination, there were 530 candidates, including 80 at 17 centres overseas. In October 1955, and April 1956, 965 candidates attended the Professional Interview including 275 at 41 centres overseas.

34. **Bayliss Prize.**—For the April 1955 Examination, the Bayliss Prize was awarded to Mr Cheuk Chi Wong, Stud.I.C.E., of Hong Kong, and for the October 1955 Examination to Mr Trevor Kenneth Newson, Stud.I.C.E., of Woodbridge, Suffolk.

35. **Research.**—The main Committee is re-examining its terms of reference, and a progressively forward policy will be pursued. One new committee has been appointed and one has completed its work and been dissolved. The following is a summary of the work of the Research Committee:—

36. *Abstracting.*—Investigations into the probable costs of producing comprehensive abstracts on civil engineering, and the possible demand for such a publication outside the membership of the Institution are continuing. A list of the most important current publications of abstracts used in the civil engineering field and produced in the United Kingdom has been supplied to the British Section of the EUSEC Working Party on Abstracting Services, who are preparing a short list of available publications covering all aspects of engineering.

37. *Coast protection.*—A bibliography is being prepared and a copy will be supplied to the International Commission on Coastal Sedimentation which is collecting information on erosion and sedimentation processes of coast lines throughout the world.

38. *Compressed air.*—There are still a few details in the proposed Diving and Compressed Air Special Regulations on which agreement has to be reached between the Committee and the Ministry of Labour and National Service.

39. *Erosion of earthen banks.*—One of the Departmental Committees set up as the result of recommendations in the Waverley Report is studying this problem, and the Institution Committee has, therefore, been dissolved.

40. *Hydraulics.*—The "Review of Recent Developments in Hydraulics", prepared by three sub-committees, was published in the Proceedings for December 1955, and copies are available in excerpt form. The Sub-Committee on Rainfall and Run-off has collected information to enable the "Interim Report of the Committee on Floods in Relation to Reservoir Practice", first published in 1933, to be brought up to date.

41. *Mining subsidence.*—A considerable amount of information has been collected and the four sub-committees are considering this with a view to producing a comprehensive report.

42. *Pile driving.*—This Committee has been resuscitated and is preparing a programme for its future activities.

43. *Prestressed concrete development.*—A first draft of a review of developments in recent years has been prepared and will be published in a few months. The fourth

Supplement to the "Bibliography on Prestressed Concrete", for the year 1954, has been published and further supplements, for 1955 and 1956, are being prepared.

44. *Sea action.*—The tests on timber (Series XIII) specimens at Colombo, Singapore, and Upnor are continuing.

45. *Soil mechanics and foundations.*—The seventh "Supplement to the Bibliography on Soil Mechanics", for the year 1954, has been published and further supplements, for 1955 and 1956, are being prepared.

46. *Vibrated concrete.*—The report of the Committee, "The Vibration of Concrete", has been approved and is being published.

47. *British Standards Institution.*—A number of draft British Standards received for comment have been referred to members conversant with the subject matter of the drafts, and any comments made have been forwarded to the British Standards Institution. Invitations to represent the Institution on new Technical Committees have been accepted by a number of members during the year.

48. **Codes of Practice.**—The drafting Panels have completed their consideration of the many comments received on the circulated drafts of Civil Engineering Codes of Practice No. 3: Earthworks, and No. 6: Traffic Bearing Structures—Pavings. The final drafts of both Codes are being prepared.

49. A new drafting Committee has been set up to prepare the amendments required to bring up to date "Civil Engineering Code of Practice No. 1: Site Investigations".

50. The "Code of Practice for the Design and Construction of Reinforced Concrete Structures for the Storage of Liquids" is being revised by a new drafting Committee,

51. **Public Relations.**—Two Christmas Lectures for Boys were arranged at the Institution:—

"Introduction to atomic energy," by Major-General S. W. Joslin, C.B., C.B.E., M.A., M.I.Mech.E., M.I.E.E.

"Railway motive power to-day and to-morrow," by Cecil J. Allen, F.R.S.A., M.Inst.T., A.I.Loco.E.

52. **Relations with other Organizations.**—The closest association has continued to exist, particularly between the three major Institutions. The Councils of the Institute of Marine Engineers, the Institution of Gas Engineers and the Institution of Municipal Engineers have now become partners in the Part I Examination. The question of higher technological education to which reference was made in the Council's last Annual Report continues to be actively pursued.

53. **Accounts.**—The accounts for the year ending the 31st March, 1956, which have been duly audited, are detailed in Appendix V of this Report and may be summarized briefly as follows:—

(a) The Total Income for the year amounted to . . . . . . . £107,287
(as compared with £99,628 last year); including £414 for Income Tax recovered. Subscriptions, Entrance Fees, and Examination Fees totalled £99,165 (as compared with £91,741 last year), and Dividends and Interest received amounted to £2,808 (as compared with £2,377 last year).

(b) The Total Expenditure charged against the year's Income amounted to . . . . . . . . . . . . . . . . £114,683 (as compared with £91,422 last year).

(c) The General Revenue Account therefore results in a debit balance on the year of . . . . . . . . . . . . . . . . £7,396

(d) The General Revenue Account Surplus amounted to £27,706 on the 31st March, 1956, made up as follows:—

| | |
|---|---|
| Balance brought forward 1st April, 1955 . . . . . . . . | £35,102 |
| Less Deficit for year to 31st March, 1956 . . . . . . . | £7,396 |
| | £27,706 |

(e) Cash at Bankers and in hand amounted to £46,777 (compared with £54,516 last year) at the close of the financial year owing to the receipt, as in past years, of a substantial proportion of the current subscriptions during the first quarter. This balance is required to finance expenditure during the remainder of the year.

(f) The actual expenditure during the year on "Publications Account" amounted to £45,291 (compared with £37,354 last year), of which £29,412 represented the cost of the Proceedings, etc. This expenditure was relieved by credits for advertisements, sales, etc., of £21,562 (against £18,658 last year), leaving the net expenditure for the year at £23,729 (compared with £18,696). There will unfortunately be a large increase during 1956 due to increased printing and postage costs.

(g) The Repairs and Renewals Reserve credit balance has been increased by £1,716 during the year, viz. from £2,463 to £4,179. Many arrears of maintenance have now to be carried out and a programme is being planned.

(h) On Trust Funds Income Account was received a total of £2,330 and the expenditure amounted to £1,555.

(j) During the year, sums of £27 in interest and £11 for sales of reports, etc., have been credited to the research into the Deterioration of Structures exposed to Sea Action.

(k) Rising costs, especially in printing and postage, have given much concern to the Council and are retarding the objects for which the Institution was founded. Means for improving the situation will be placed before members shortly.

54. **Prizes.**—A Charles Hawksley Prize of £150 for the 1955 Competition was awarded to Mr G. W. Robinson, Stud.I.C.E., and consolation prizes to Mr E. J. W. Henry, A.M.I.C.E. (£125), and to Mr G. W. H. Taylor, B.Sc., Grad.I.C.E. (£50).

55. **Fellowships and Scholarships.**—The 1955–56 Radley Research Studentship was awarded to Mr J. M. Lomax, B.Sc., Grad.I.C.E., to enable him to undertake post-graduate research on the influence of flange rigidity on the post-buckled behaviour of the web plate of plate girders at the University College of Swansea.

56. **Rockefeller Foundation Bursaries in Public Health Engineering.**— —Seven awards totalling £3,000 were made for the academic year 1955–56; six for post-graduate study, and one for research.

7. **Conversazione.**—The Conversazione was held on the evening of the 23rd June, 1955, when 1,360 members, guests, and ladies were present.

8. **Graduates' and Students' Conversazione.**—This was held on the 21st October 1955, and was attended by 475 Graduates and Students and their ladies. Models were exhibited.

9. **Annual Dinner.**—This was held on 19 April, 1956, at the Dorchester Hotel, when the Rt Hon. Harold Watkinson, M.P., proposed the toast of the Institution to which the President replied; and the Very Reverend A. C. Don, K.C.V.O., D.D., the Dean of Westminster, replied to the toast of the guests, proposed by Mr H. J. F. Gourley, Vice-President. There were 547 present, including guests.

00. **Nominations and Appointments.**—The following appointments have been made or renewed by the Council during the year:—

| | |
|---|---|
| Sir Arthur Whitaker, K.C.B., M.Eng. | British National Committee, Permanent International Association of Navigation Congresses. |
| Sir Arthur Whitaker, K.C.B., M.Eng.<br>Mr G. A. Wilson, M.Eng. | British Organizing Committee, 19th International Congress, Permanent International Association of Navigation Congresses. |
| Mr D. J. MacLean, B.Sc.<br>Mr A. H. Toms, B.Sc.(Eng.) | British National Committee, International Society of Soil Mechanics and Foundation Engineering. |
| Mr J. A. Banks, O.B.E. | British National Committee, World Power Conference. |
| Mr R. Jones, Ph.D.<br>Mr F. N. Sparkes, M.Sc. | British National Committee for Non-Destructive Testing. |
| Mr Ralph Freeman, C.B.E., M.A.<br>Mr L. Scott White, O.B.E. | National Consultative Council, Ministry of Works. |
| Brigadier C. C. Parkman, O.B.E. | North West Regional Building and Civil Engineering Joint Committee, Ministry of Works. |
| Mr W. C. Andrews, O.B.E.<br>Mr L. Scott White, O.B.E. | District Surveyors' Examination Board, London County Council. |
| Mr J. E. Swindlehurst, O.B.E., M.A. | National Road Safety Committee, Royal Society for the Prevention of Accidents. |
| Sir Herbert Manzoni, C.B.E. | Governing Body, Loughborough College of Technology. |
| Mr A. C. Dean, M.C., M.Sc. | Court of Governors, Manchester College of Science and Technology. |
| Mr A. F. Holt | Governing Body, Croydon Technical College. |
| Mr Ralph Freeman, C.B.E., M.A. | Governing Body, South East London Technical College. |
| Mr J. H. W. Turner, B.Sc. | Governing Body, Westminster Technical College. |
| Mr R. Glossop, B.Sc. | Governing Body, Camborne School of Metalliferous Mining, Cornwall. |
| Professor R. J. Cornish, M.Sc.<br>Mr P. E. Sleight, M.Eng. | Board of Studies in Engineering of the National Council for Awards in Technology. |
| Mr. P. E. Sleight, M.Eng.<br>Mr G. A. R. Sheppard, M.A. | London and Home Counties Regional Advisory Council for Higher Technological Education. |

| | |
|---|---|
| Mr N. A. Matheson<br>Mr J. Paton Watson, C.B.E. | Engineering Sub-Committee, Regional Council for further education for the South West. |
| Mr C. E. Boast, O.B.E., M.C. | Mechanical Engineering Advisory Committee, Croydon Technical College. |
| Brigadier C. C. Parkman, O.B.E. | Engineering Advisory Committee, Liverpool Education Committee. |
| Mr P. E. Sleight, M.Eng.<br>Mr J. H. W. Turner, B.Sc. | Engineering Joint Examination Board. |
| Mr J. Linton Bogle, M.C., B.Eng. | Codes of Practice Committee for Civil Engineering. |
| Mr Oscar Faber, C.B.E., D.Sc.(Eng.)<br>Professor F. Webster, M.C., M.Eng. | Committee on Code of Practice for the design and construction of reinforced-concrete structures for the Storage of Liquids. |
| Colonel C. M. Norrie, D.S.O., B.Sc.<br>Mr V. F. Bartlett, B.Sc.<br>Mr J. H. Jellett, O.B.E., M.A. | Compressed Air Committee. |
| Mr H. Shirley Smith, O.B.E., B.Sc. (Eng.)<br>Mr J. H. W. Turner, B.Sc.<br>Sir Hubert Walker, C.B.E. | Board of the Professional Engineers' Appointments Bureau. |
| Mr H. R. Lupton, O.B.E., M.A. | Panel of the Electrical Research Association. |
| Professor S. C. Redshaw, D.Sc., Ph.D. | Athlone Fellowship Managing Committee. |
| Mr T. A. L. Paton, B.Sc. | Standing Joint Committee with the Federation of Civil Engineering Contractors for the Training of Civil Engineers. |
| Colonel A. Borlase, T.D.<br>Mr C. B. Townend, C.B.E., B.Sc. | Standing Joint Committee with the Institution of Municipal Engineers for the Training of Civil Engineers. |

Mr A. C. Hartley, C.B.E., B.Sc.(Eng.), represented the Institution at the 75th Anniversary Celebrations of the American Society of Mechanical Engineers, held in Boston, Massachusetts, in June 1955.

Sir Herbert Manzoni, C.B.E., represented the Institution at the 10th International Road Congress, held in Istanbul, from 25 September to 1 October, 1955.

Mr W. K. Wallace, C.B.E., President I.C.E., represented the Institution at the Centenary Celebration of the foundation of Verein Deutscher Ingenieure held in Berlin from 12 to 15 May, 1956.

Mr A. S. Hamilton, B.Sc., represented the Institution at the Health Congress arranged by the Royal Society of Health at Blackpool in April 1956.

Mr J. A. Banks, O.B.E., has agreed to represent the Institution at the 5th World Power Conference to be held in Vienna from 17 to 23 June, 1956.

Mr J. L. White, C.B.E., D.L., B.Sc., has agreed to represent the Institution at the General Assembly of the International Union for the Protection of Nature to be held n Edinburgh from 19 to 28 June, 1956.

61. **International Engineering Congresses**

(a) The British National Society of the International Society of Soil Mechanics and Foundation Engineering have held three informal discussion meetings at the Institution. The Council have agreed that the headquarters of the Fourth International Conference of the Society, from 12 to 24 August, 1957,

shall be at the Institution and that the meetings of the Conference shall be held in the Great Hall.

(b) On the initiative of the British National Committee of the Permanent International Association of Navigation Congresses an Organizing Committee was set up for XIXth Congress to be held in London in the fortnight commencing 8 July, 1957. Sir Arthur Whitaker (Vice-President of the Institution), who with Mr G. A. Wilson, M.Eng., represent the Institution on this Committee, was appointed Chairman. The Organizing Committee and its Sub-Committees have been engaged in preparing the programme of meetings, visits, etc. for the Congress which will be centred on the Institution building. The Ministry of Transport made available the services of Mr A. C. Morrison, M.A., as Secretary of the Organizing Committee for the Congress.

(c) The Report by the British National Committee on the depths of water to be provided in seaports and approach channels was completed during the year and submitted to the International Association and has since been published.

(d) The British Section of the Permanent International Association of Navigation Congresses adopted a new Constitution in 1955 and Sir Arthur Whitaker was appointed Chairman of the British Section and of the British National Committee for the coming year.

(e) The British National Committee of the International Commission of Irrigation and Drainage, under the Chairmanship of Sir Claude Inglis, C.I.E., M.A.I., M.I.C.E., F.R.S., met five times during the year. The Committee has had under consideration British participation in the next Congress due to take place in 1957 in the United States of America and hopes to arrange for some seven Papers from this country. The Committee appointed an Executive Sub-Committee consisting of Sir Claude Inglis, Mr E. A. G. Johnson, C.B.E., B.Sc.(Eng.), M.I.C.E., and Mr W. Allard, O.B.E., B.Sc., M.I.C.E., to advise on day-to-day matters.

52. **British Nuclear Energy Conference**—The inaugural meeting of the Conference was held at the Institution on Wednesday, 30 November, 1955. About [illegible],000 members of the Institution, the Institution of Mechanical Engineers, the Institution of Electrical Engineers, the Institute of Physics, and the Institution of Chemical Engineers were present. Sir Christopher Hinton, Chairman of the Board, was in the Chair. The following Papers were presented:—

"The United Kingdom Atomic Energy Authority and its functions," by Sir John Cockcroft, K.C.B., C.B.E., M.I.Mech.E.(Hon.), M.I.E.E., Pres.Inst.P., F.R.S.

"The place of nuclear energy in United Kingdom power development," by V. A. Pask, C.B.E., M.I.Mech.E., M.I.E.E., and J. C. Duckworth, B.A.

"Health and safety in a nuclear power industry," by A. S. McLean, M.B., Ch.B., D.I.H., and W. G. Harley, M.Sc., Ph.D.

"The use of research reactors in nuclear power development," by H. J. Grout, B.Sc.(Eng.), A.C.G.I., A.M.I.Mech.E.

The Papers and discussions were published in the January 1956 issue of the Journal of the British Nuclear Energy Conference. In addition, approximately one meeting per month was arranged by the one or other of the five sponsoring societies.

63. The Paper on "The control, conveyance, treatment, and disposal of radioactive effluents from the Atomic Weapons Research Establishment, Aldermaston," by Mr W. L. Wilson, O.B.E., B.Sc.(Eng.), A.M.I.C.E., M.I.Mech.E., Mr P. A. F. White, B.Sc., M.I.Chem.E., and Mr J. G. Milton, M.I.Mech.E. presented before a meeting of the Public Health Division was included in the Programme of the Conference as a Paper sponsored by the Institution.

64. **The Roll.**—The Roll of the Institution on the 31st March, 1956, stood at 21,485, the changes which have taken place in it during the year being shown in the Table given below:—

| | 1st April, 1954, to 31st March, 1955 | | | | | | | 1st April, 1955, to 31st March, 1956 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Honorary Members | Members | Associate Members | Associates | Graduates | Students | Totals | Honorary Members | Members | Associate Members | Associates | Graduates | Students | Totals |
| Numbers at commencement | 16 | 2413 | 10660 | 33 | 2502 | 4350 | 19974 | 16 | 2456 | 11123 | 34 | 3135 | 3942 | 20706 |
| Transfers: | | | | | | | | | | | | | | |
| Associate Members to Members | .. | +114 | −114 | .. | .. | .. | | .. | +172 | −172 | .. | .. | .. | |
| Elections | .. | 8 | 713 | 3 | .. | .. | | 2 | 5 | 748 | 1 | .. | .. | |
| Admissions | .. | .. | .. | .. | 915 | 759 | +2426 | .. | .. | .. | .. | 821 | 894 | +2493 |
| Restored to Roll | .. | 2 | 20 | .. | 1 | 5 | | .. | 1 | 10 | .. | 5 | 6 | |
| Deceased | .. | 61 | 66 | 2 | 2 | 4 | | .. | 78 | 90 | .. | 5 | 2 | |
| Resigned | .. | 16 | 54 | .. | 11 | 41 | | .. | 10 | 49 | .. | 9 | 43 | |
| Erased | .. | 4 | 35 | .. | 1 | 48 | | .. | 4 | 22 | .. | 11 | 51 | |
| Elected as Associate Members | .. | .. | .. | .. | 268 | 89 | | .. | .. | .. | .. | 352 | 49 | |
| Admitted as Graduates | .. | .. | .. | .. | .. | 554 | −1694 | .. | .. | .. | .. | .. | 491 | −1714 |
| Removed as over-age | .. | .. | .. | .. | .. | 430 | | .. | .. | .. | .. | 1 | 432 | |
| Failed to complete: | | | | | | | | | | | | | | |
| Transfer | .. | .. | .. | .. | .. | .. | | .. | .. | .. | .. | .. | .. | |
| Election | .. | .. | 1 | .. | .. | .. | | .. | .. | 3 | .. | .. | .. | |
| Admission | .. | .. | .. | .. | 1 | 6 | | .. | .. | .. | .. | 7 | 5 | |
| | | | | | | | +732 | | | | | | | + 779 |
| Numbers at termination | 16 | 2456 | 11123 | 34 | 3135 | 3942 | 20706 | 18 | 2542 | 11545 | 35 | 3576 | 3769 | 21485 |

The full list of deaths and resignations is given in Appendix IV, and the Council record with especial regret the deaths of Sir Richard Augustine Studdert Redmayne, K.C.B., M.Sc. (Past-President), Major-General Sir Clive Selwyn Steele, K.B.E., D.S.O., M.C., V.D., B.C.E. (Member of Council), Sir Athol Lancelot Anderson, K.C.B. (former Member of Council), and Lieutenant-Colonel Graham Townsend Bennett, O.B.E., B.Sc. (former Member of Council).

65. **Honours.**—The following were the recipients of Honours conferred during the year:—

*Knighthood*

Mr T. A. W. Foy, C.S.I., C.I.E., B.Sc., M.I.C.E.

Mr H. F. H. Jones, M.B.E., M.A., M.I.C.E.

Mr G. M. McNaughton, C.B., B.Sc., M.I.C.E.

Professor A. G. Pugsley, O.B.E., D.Sc.(Eng.), M.I.C.E., F.R.S.

Mr Justice Arthur Tyndall, C.M.G., A.M.I.C.E.

*C.M.G.*
Mr H. A. W. Morrice, B.A., M.I.C.E.
Mr C. T. F. Serjeant, B.Sc.(Eng.), A.M.I.C.E.

*K.C.B.*
Sir George Mowlem Burt, M.I.C.E.
Mr William Hudson, B.Sc.(Eng.), M.I.C.E.

*K.B.E. (Civil)*
Sir Hugh Eyre Campbell Beaver, M.I.C.E.

*C.B.E. (Civil)*
Mr Edwin Butler, M.A., M.I.C.E.
Mr P. A. T. Chrimes, M.A., M.I.C.E.
Mr A. R. B. Edgecombe, B.Sc.(Eng.), M.I.C.E.
Mr A. R. Entrican, A.M.I.C.E.
Mr William Fairley, M.A., M.I.C.E.
Mr J. G. Taylor, M.I.C.E.

*C.B.E. (Military)*
Brigadier S. A. Stewart, O.B.E., R.E., A.M.I.C.E.

*O.B.E. (Civil)*
Mr G. L. Ackers, M.I.C.E.
Mr W. A. M. Allan, M.I.C.E.
Mr D. A. de C. Bellamy, B.Sc.(Eng.), A.M.I.C.E.
Mr J. J. Bryan, B.Sc., M.I.C.E.
Mr W. S. Catlow, A.M.I.C.E.
Mr S. B. Hamilton, M.Sc., Ph.D., B.Sc.(Eng.), M.I.C.E.
Mr J. L. S. Jeffares, B.Sc., M.I.C.E.
Mr C. M. Kerr, A.M.I.C.E.
Mr F. J. McIntosh, B.Sc., M.I.C.E.
Mr C. C. Morley, A.F.C., B.Sc., A.M.I.C.E.
Mr D. M. O'Herlihy, B.Sc.(Eng.), M.I.C.E.
Mr N. F. Richards, B.Sc., M.I.C.E.
Mr C. H. Smith, A.M.I.C.E.
Mr H. F. Toogood, M.I.C.E.
Mr R. V. Trace, A.M.I.C.E.

*O.B.E. (Military)*
Lieutenant-Colonel A. P. de T. Daniell, M.C., T.D., M.A., A.M.I.C.E.
Wing Commander I. C. Hover, A.M.I.C.E.

*M.B.E. (Civil)*
Mr D. A. Alves, A.M.I.C.E.
Mr Harry Cheetham, B.A., A.M.I.C.E.
Mr E. S. Chiappe, A.M.I.C.E.
Mr W. B. Hudson, M.I.C.E.

66. **Acquisitions**

(a) The Council have received, on behalf of the Institution, a portrait of Mr David M. Watson (President 1954–1955) painted by Edward I. Halliday.

(b) The Council have accepted, on behalf of the Institution, a portrait of Sir Charles Fox, father of Sir Douglas Fox, Past-President of the Institution, presented by Mr N. Teulon-Porter.

(c) A Model of his invention of a flexible rudder for vessels on inland waterways, presented by Colonel R. D. T. Alexander, D.S.O., O.B.E., T.D., former Member of Council.

(d) The Council during the year commissioned posthumous portraits of previous Secretaries of the Institution as follows:—Dr Tudsbery and Dr Jeffcott, painted by Robert Swan, and Mr E. Graham Clark painted by John Whitlock. These portraits will, with the existing portraits of Charles Manby and James Forrese, complete the Institution's pictorial records of its past Secretaries.

67. **Institution Secretariat.**—Based on a report by a firm of management consultants, a re-organization of the Secretariat has been put in hand and is nearly completed. There had been no major examination of the organization since about 1935 and the functions and activities of the Institution have, of course, increased and developed greatly since then. A third Assistant Secretary, Mr M. E. Constant, B.Sc., A.M.I.C.E., was appointed. Preparations for a mechanized procedure for subscription accounting, which will reduce the amount of clerical work involved, are in hand.

## APPENDIX I

### ORDINARY MEETINGS

Presidential Address of Mr W. K. Wallace, C.B.E.

The Parsons Memorial Lecture on "The development of the gas turbine," by Sir Harold Roxbee Cox, D.Sc., Ph.D., M.I.Mech.E., F.R.Ae.S.

"The experimental and mathematical analysis of arch dams, with special reference to Dokan," by Professor D. N. de G. Allen, M.A., Letitia Chitty, M.A., A.M.I.C.E., Professor A. J. S. Pippard, M.B.E., D.Sc., M.I.C.E., F.R.S., and R. T. Severn, Ph.D.

"The design and construction of Aden Oil Harbour," by J. E. G. Palmer, M.A., M.I.C.E., and Harold Scrutton, M.I.C.E.

"Methods of using long-term storage in reservoirs," by H. E. Hurst, C.M.G., M.A., D.Sc.

"The Glen Shira hydro-electric project," by John Paton, M.I.C.E.

The James Forrest Lecture on "Marine physics," by G. E. R. Deacon, C.B.E., D.Sc., F.R.S.

### JOINT MEETINGS

With the Institution of Mechanical Engineers:

"The development of a mechanical-draught water-cooling tower," by L. G. Smith, M.I.C.E., and G. J. Williamson, B.A., M.I.Mech.E.

With the Institution of Mechanical Engineers and the Institution of Electrical Engineers:

"Advanced courses for engineers in industry,"

Part I: by H. D. Morgan, M.Sc.(Eng.), M.I.C.E.

Part II: by Professor G. F. Mucklow, D.Sc., M.I.Mech.E.,

Part III: by Willis Jackson, D.Sc., D.Phil., M.I.Mech.E., M.I.E.E., F.R.S. (at the Institution of Mechanical Engineers).

With the Institution of Electrical Engineers:

"The Pimlico District Heating Undertaking—costs and financial results," by Bryan Donkin, B.A., A.M.I.C.E., M.I.E.E., C. M. Johnston, B.Sc., A.M.I.E.E., and Edward Ockenden.

The Graham Clark Lecture on "The impact of engineering on society," by Sir Maurice Bowra, F.B.A., M.A.
(at the Institution of Mechanical Engineers).

With the Institution of Mechanical Engineers:
"Pumping problems: present and future," by Herbert Addison, O.B.E., M.Sc., M.I.C.E., M.I.Mech.E.

## SUPPLEMENTARY MEETINGS

"The raising and strengthening of the Steenbras Dam," by S. S. Morris, B.Sc.(Eng.), M.I.C.E., M.Amer.Soc.C.E., and W. S. Garrett, B.Sc., A.M.I.C.E. (presented simultaneously to the South African Institution of Civil Engineers).

The Rankine Memorial Lecture "W. J. M. Rankine: a commemorative lecture," by Sir Richard Southwell, M.A., LL.D., Hon.M.I.Mech.E., F.R.S. (a repetition of a lecture delivered to the University of Glasgow).

## ENGINEERING DIVISION MEETINGS

### AIRPORT DIVISION

"Selected aspects of the geometric design of airports," by J. H. Jones, M.S., A.M. Amer.Soc.C.E.

"The investigations, design, and construction of Paya Lebar Airport, Singapore," by J. J. Bryan, B.Sc., M.I.C.E.

### HYDRAULICS DIVISION

"Experiments with hydraulic models of Port Lyttelton," by R. C. H. Russell, M.A., A.M.I.C.E., A.M.I.Mech.E.

"Some hydraulic investigations in connexion with the Wadi Tharthar Project, Iraq," by A. R. Thomas, O.B.E., B.Sc.(Eng.), M.I.C.E.

### MARITIME AND WATERWAYS DIVISION

"The failure and repair of Ridham Dock," by R. G. T. Lane, B.Sc., M.I.C.E., and G. T. Gregorian.

"Reconstruction of the Gallions Lower Entrance Lock at the Royal Docks of the Port of London Authority," by J. A. Fisher, M.I.C.E.

Symposium on general cargo handling:
"The design of ships from the cargo-handling point of view," by J. A. H. Lees, B.Sc., M.I.N.A.
"Civil engineering structures," by N. A. Matheson, M.I.C.E., M.I.Mech.E.
"The supply and maintenance of mechanical equipment," by J. C. Shire, A.M.I.Mech.E., A.M.I.N.A.
"Handling of port traffic," by E. S. Tooth.

### PUBLIC HEALTH DIVISION

"The development of sewage treatment, in the City of Coventry," by Granville Berry, M.I.C.E., and C. R. Deeley, D.F.M.

"The Caithness regional water supply scheme," by W. A. R. Baker, B.Sc.(Eng.), M.I.C.E., W. M. Jollans, M.A., A.M.I.C.E., and J. N. Dale.

"The control, conveyance, treatment and disposal of radio-active effluents from the Atomic Weapons Research Establishment, Aldermaston," by W. L. Wilson, O.B.E., B.Sc.(Eng.), A.M.I.C.E., M.I.Mech.E., P. A. F. White, B.Sc., M.I.Chem.E., and J. G. Milton, M.I.Mech.E. (included in the programme of the British Nuclear Energy Conference).

"The construction of Middleton connecting sewer in North Manchester," by E. H. Collier, A.M.I.C.E.

### RAILWAY DIVISION

"Uses of aerated cement grout and mortar in stabilization of slips in embankments, large-scale tunnel repairs, and other works," by M. C. Purbrick, B.Sc.(Eng.), A.M.I.C.E., and D. J. Ayres.

"Consolidation of ballast," by I. G. White, A.M.I.C.E.
"Earth movement affecting L.T.E. railway in deep cutting east of Uxbridge," by J. D. Watson, M.B.E., B.Sc.(Eng.), M.I.C.E.
Informal Discussion on "Mechanized and mobile gang maintenance of track." Introductory notes by H. H. Robinson, A.M.I.C.E., I. G. White, A.M.I.C.E., and J. R. Hammond, M.B.E., B.Sc.(Eng.), A.M.I.C.E.

### ROAD DIVISION

"The planning of ring roads, with special reference to London," by F. A. Rayfield, M.I.C.E.
"Oxton by-pass extension," by R. A. Kidd, B.Sc., M.I.C.E.
"Design of road intersections," by Kenneth Summerfield, M.Sc., A.M.I.C.E.

### STRUCTURAL AND BUILDING DIVISION

"Prestressed concrete as applied to building frames," by Francis Walley, M.Sc., A.M.I.C.E., and H. C. Adams, B.Sc.
"The stanchion problem in frame structures designed according to ultimate carrying capacity," by M. R. Horne, M.A., Ph.D., A.M.I.C.E.
"The roofing of Cleadon Reservoir," by N. J. Ruffle, B.Sc.(Eng.), A.M.I.C.E., and Hugh Tottenham, M.A.
"The basis for design of beams and plate girders in the revised British Standard 153," by O. A. Kerensky, B.Sc., M.I.C.E., A. R. Flint, B.Sc., Ph.D., and W. C. Brown, B.Sc., Ph.D.
"Experimental verification of the strengths of plate girders designed in accordance with the revised British Standard 153: tests on full-size and on model plate girders," by Eric Longbottom, B.Sc., A.M.I.C.E., and Jacques Heyman, M.A., Ph.D., A.M.I.C.E.
"The allowable settlements of buildings," by Professor A. W. Skempton, D.Sc.(Eng.), A.M.I.C.E., and D. H. MacDonald, Ph.D.

### WORKS CONSTRUCTION DIVISION

"The diversion of the Annalong River into the Silent Valley Reservoir," by C. F. Colebrook, T.D., Ph.D., B.Sc.(Eng.), M.I.C.E.
"Construction of 60-in.-dia. outfall sewer for Morecambe and Heysham Corporation," by J. K. Brooks, M.I.C.E., and J. S. D. Brown.
"Toll highways: their economics and construction,"
Part 1: "Toll roads," by H. D. Morgan, M.Sc.(Eng.), M.I.C.E.
Part 2: "Toll bridges and tunnels," by V. F. Bartlett, B.Sc.(Eng.), M.I.C.E., and H. Shirley Smith, O.B.E., B.Sc.(Eng.), M.I.C.E.
Part 3: "Turnpikes," by E. W. W. Richards, A.M.I.C.E.
"Kwinana jetty," by Peter Murray, B.Sc., M.I.C.E., and D. N. Collett.

## APPENDIX II

### AWARDS FOR PAPERS

The following medals, premiums, and prizes were awarded for Papers presented for discussion at Meetings in Session 1954–55 or published for written discussion in the Proceedings for 1954:—

*Telford Gold Medal*

G. W. Wilkinson, M.I.C.E. (joint Author with C. B. Townend, C.B.E., B.Sc.(Eng.), M.I.C.E.) for Paper: "Some hydraulic aspects of sewerage and sewage disposal," the special thanks of the Institution being accorded to Mr Townend, Member of Council.

*James Watt Medals*

T. G. N. Haldane, M.A., M.I.C.E., M.I.E.E., and P. L. Blackstone, T.D., M.A., M.I.E.E., for Paper: "Problems of hydro-electric design in mixed thermal-hydro-electric systems."

*Howard Gold Medals*

D. H. Little, B.Sc.(Eng.), A.M.I.C.E., and A. Augustus Smith, B.Sc.(Eng.), A.M.I.C.E., for Paper: "Some steel structural frames designed on plastic theory."

*George Stephenson Medal*

Professor R. H. Evans, D.Sc., Ph.D., M.I.C.E., for Paper: "Applications of prestressed concrete to water supply and drainage."

*Coopers Hill War Memorial Prize*

T. F. Burns, M.I.C.E., for Paper: "The design and construction of No. 8 Dry Dock at North Shields for Smith's Dock Co. Ltd."

*Baker Medal*

W. R. Schriever for Paper: "Strain measurements on the temporary road deck for the Toronto Subway."

*Telford Premiums*

P. S. A. Berridge, M.B.E., M.I.C.E., and F. M. Easton, A.M.I.C.E., jointly for Paper: "Some notes on the half-through type plate-girder railway bridge."
A. J. H. Clayton, B.Sc.(Eng.), A.M.I.C.E., for Paper: "Working capacity of roads."
P. A. Lamont, M.A., A.M.I.C.E., for Paper: "A review of pipe-friction data and formulae, with a proposed set of exponential formulae based on the theory of roughness."
D. C. Milne, B.Sc., M.I.C.E., for Paper: "The Queen Elizabeth II Dock, Eastham."
T. J. O'Kelly, B.E., for Paper: "The employment of unit hydrographs to determine the flows of Irish arterial drainage channels." In view of the death of the Author, a token bronze Telford medal was presented to his widow in lieu of the premium.
J. P. Stott, B.Sc.(Eng.), Ph.D., for Paper: "Prestressed concrete roads."
B. E. Willett, B.Sc.(Eng.), A.M.I.C.E., for Paper: "The requirements of a civil airport as typified by London Airport."

*Manby Premium*

Professor A. W. Skempton, D.Sc.(Eng.), A.M.I.C.E., for Paper: "Foundations for high buildings."

*Trevithick Premium*

C. D. C. Braine, B.Sc., M.I.C.E., for Paper: "The effect of storage on sewerage design."

*Crampton Prize*

Charles Jaeger, Dr ès Sc. Techn., for Paper: "Present trends in the design of pressure tunnels and shafts for underground hydro-electric power stations."

*Webb Prize*

R. L. McIlmoyle, M.I.C.E., and D. W. Peacock, B.Sc., jointly for Paper: "Smoke extraction from engine sheds—an account of some model and full-scale tests."

*James Forrest Medal*

R. W. Riley, B.A., Grad.I.C.E., for Paper: "A 33-in. steel pipe-line for the Daer Water Board." (Association of London Graduates and Students.)

*Miller Prizes*

D. M. Atkin, B.Eng., Stud.I.C.E., for Paper: "The filtration of public water supplies." (Midlands Association.)
M. S. Gregory, B.E., Grad.I.C.E., for Paper: "Timber-pile grid-iron for 650 ton suction dredger, Marine Board of Devonport, Tasmania." (Glasgow and West of Scotland Association.)
R. P. Johnson, B.A., Stud.I.C.E., for Paper: "The plastic design of steel structures." (Association of London Graduates and Students.)

J. L. Kay, B.Sc.Tech., Grad.I.C.E., for Paper: "Some aspects of airport development." (North-Western Association.)

R. J. Livesey, Grad.I.C.E., for Paper: "The failure and repair of a steel sheet-pile dock wall." (Glasgow and West of Scotland Association.)

James Park, B.Sc., Stud.I.C.E., for Paper: "Uplift forces in masonry dams." (Edinburgh and East of Scotland Association.)

R. W. Riley, B.A., Grad.I.C.E., for Paper: "A 33-in. steel pipe line for the Daer Water Board." (Association of London Graduates and Students.)

A. N. Schofield, Esq., B.A., Grad.I.C.E., for Paper: "Recent development of low cost pavements in Nyasaland." (Association of London Graduates and Students.)

F. K. Smith, Stud.I.C.E., for Paper: "Trial designs of decking for Clifton Suspension Bridge, with special reference to maintenance and corrosion." (South Western Association.)

The following medals and premiums were awarded on the result of annual competitions:—

*Institution Medal and Premium (London University)*

V. S. Clemow, Stud.I.C.E., for Paper: "The design and construction of permanent way." (King's College.)

*Institution Medal and Premium (Local Associations)*

R. J. Livesey, Grad.I.C.E., for Paper: "The failure and repair of a steel sheet-pile dock wall." (Glasgow and West of Scotland Association.)

## APPENDIX III *

### GLASGOW AND WEST OF SCOTLAND ASSOCIATION

Mr N. M. Brydon, M.B.E. (M), who was elected Chairman in succession to Mr Stanley D. Canvin (M), took as the subject of his inaugural address "The joys and sorrows of contracting". The address was an amusing and penetrating account of the varied experiences in the contracting field.

The Lord Provost, Andrew Hood, Esq., and the Corporation of the City of Glasgow honoured the Association by granting a Civic Reception on 30th September, 1955, to mark the 70th anniversary of the inception of the Association. The Lord Provost accompanied by the Lady Provost and Magistrates received the Guests in the Satinwood Salon at the City Chambers. The address of welcome from the Lord Provost followed to which the Chairman, Mr Stanley D. Canvin and the President, Mr David M. Watson replied. Upon the invitation of the Lord Provost, Mr J. A. Warren (M), first chairman of the Association in the year 1884, also spoke from the platform with wit and wisdom. The Secretary and Mrs McDonald were also present. The members and guests, totalling between five and six hundred, enjoyed the hospitality and entertainment provided by the Corporation, which consisted of a concert, dancing and running buffet.

Papers presented at meetings covered a wide field and included "The civil engineer's work in modern coal mining," by Mr H. R. King of the National Coal Board; "Some civil engineering aspects of atomic power generation," by Mr I. Davidson (AM); and "The Railway Modernization Plan with particular reference to civil engineering," by Mr M. G. Maycock (M).

A lecture "Corrosive resistant structure" was given by Mr J. Gall Smith (M), and a joint meeting was held with the local branches of each of the Institution of Structural Engineers and Institution of Electrical Engineers.

In addition to these meetings four were held at Inverness.

A small sub-committee has been assisting the Chairman of the Graduates' and Students' Section in considering the various ways in which papers can be presented, and advance copies of many of the previous papers have been previously circulated.

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* In this Appendix the following abbreviations are used:—Member (M); Associate Member (AM); Graduate (G); Student (S).

At the Annual Dinner at Glasgow in November 1955 there were 288 members and guests including the President and Secretary. The Institution Medal (Local Associations) 1955 was presented at this dinner to Mr R. J. Livesey (G), by the President. The award of Miller Prizes to Mr Livesey and Mr M. S. Gregory (G), has also been announced.

The summer meeting last year held at Turnberry was not as well attended as usual.

A Luncheon meeting was again arranged and proved to be successful and well attended.

Several visits were arranged and included those to works in Ayrshire, comprising new colliery headgear and a newly completed sewage works; service water-towers under construction for the Glasgow Corporation; a new quay wall at Shieldhall and the Coltness cement works.

The Association's representative on the Council has continued to be Mr William Linn (M), a Past-Chairman of the Association.

## MIDLANDS ASSOCIATION

The Chairman for the session has been Mr R. H. Lee (M) who succeeded Mr J. E. Dumbleton (M). Mr A. Burrows (M) relinquished the position of Hon. Secretary after five years service, and was succeeded by Mr D. Lumbard (M). Mr J. Cook (G) accepted the duties of Hon. Assistant Secretary from Mr J. M. Loveday (G) who had served for three years.

The most important development during the year has been in the East Midlands. At the commencement of the session a "Shadow Committee" was elected and arranged a series of meetings which have been so enthusiastically attended that Council has been asked to consider the formation of a separate Association for the area comprising Lincolnshire (including the Soke of Peterborough), Derbyshire (excluding the High Peak District), Nottinghamshire, Leicestershire and Rutland.

The Chairman gave his address at Birmingham and Nottingham, and discussed the evolution of a new approach to Water Supplies. Local sources of supply were becoming increasingly inadequate and it was necessary to reduce the number of undertakings in accordance with a National policy. He referred to the growth in the demand for water for industrial uses and concluded with a review of research into recharging of aquifers and demineralization of sea water.

Twenty Ordinary Meetings were held. Eight in Birmingham, seven in Nottingham, and three in Loughborough. The following subjects were discussed:—Construction in Western Europe; Atomic Factories; Prestressed concrete for buildings and bridges; Sewage treatment at Coventry; Waterways; Motorways; Factory Design; The Queen Elizabeth Dock, Eastham; and New Works at Derby Station.

Professor A. J. S. Pippard (Vice-President), attended a meeting in Birmingham, and the Association welcomes the closer link with Headquarters that such visits help to establish.

The annual joint meeting with the local associations of the Institutions of Mechanical and Electrical Engineers was again very well attended. The subject of the lecture was "The recent search for the salvage of the Comet aircraft, near Elba".

There have been four visits to works: to the Hydraulic Works at Wallingford; with the Institution of Municipal Engineers to various works at progress in the Nottingham area; to the new sewage works at Coventry, and the reconstruction of the City Centre; and a joint visit with the Institution of Structural Engineers to Hams Hall Power Station. The Sixth annual visit to the Stratford-on-Avon Memorial Theatre was very popular, and the party was accompanied by the then President, Mr David M. Watson, and his wife. The President and the Lord Mayor of Birmingham were principal guests at the Annual Dinner.

The Graduates' and Students' Section held five meetings, including a joint one with the Mechanicals. The support was not very encouraging but the standard of the papers and the discussion was good, and one Author was awarded a Miller Prize. The joint Dance with the Electricals and Mechanicals was a great success.

The City of Birmingham Education Department conducted a series of lectures to schools during the Christmas Holidays and one afternoon was devoted to engineering. The Graduates' and Students' Vice-Chairman represented the Association and spoke about civil engineering as a career.

Mr C. A. Risbridger (M) continued to represent the Association on the Council, and Sir Herbert Manzoni (M) continued to serve as a member of Council.

## SOUTH-WESTERN ASSOCIATION

The Chairman for this Session was Mr E. N. Underwood (M), who took as the subject for his Address, some of the unusual solutions to engineering problems which have arisen in the course of his practice as a Consulting Engineer.

Mr A. G. Tookey (AM) found it necessary to resign the office as Honorary Treasurer for health reasons, after six years of continuous service and received a presentation from the Association at the Annual General Meeting. The Committee appointed Mr Robert Akerman (AM) to succeed Mr Tookey.

It was decided to reduce the number of ordinary meetings from 15 to 13, total, and also to include in the programme a larger number of lectures, rather than the more formal "papers", on civil engineering subjects. The innovation has helped to raise the average attendance from 34 members to 39 per meeting.

Four visits to works were arranged of which two each occupied a whole day; all four meetings were well attended—some 137 members taking part.

A Student member of the Association, Mr R. K. Smith, was awarded a Miller Prize for his Paper entitled "Considerations in the design of decking for Clifton suspension Bridge". A successful evening was held in Bristol to discuss "Problems and viewpoints of a main contractor".

The Annual Dinner and Dance was held in November and the company of 140 members and their guests included the President of the Institution, Mr W. K. Wallace, and the Secretary, Mr A. McDonald. Also, nine monthly luncheons were held in Bristol each of which was followed by a short talk on some topical engineering matter and attended by a total of 182 members and guests.

The Association was very happy to congratulate Professor Alfred G. Pugsley, O.B.E., D.S.O., F.R.S., M.I.C.E., in the honour of knighthood conferred upon him in January.

## NORTHERN IRELAND ASSOCIATION

Mr J. R. W. Murland (M) succeeded Mr E. A. F. Johnston (M) as Chairman for the Session and delivered his address on the 17th October, 1955, which included an interesting description of various works carried out by a Consulting Engineer.

Seven ordinary meetings were held. As is the custom, one was organized by the Graduates and Students. A combined meeting—additional to the ordinary programme—of the Institutions of Mechanical, Electrical and Civil Engineers was also held.

During the Session three visits have been arranged; also five visits for Graduates and Students.

The President and Secretary of the Institution visited Belfast for the Annual Dinner of the Association held in the Midland Hotel on the 11th February, when about 94 members and guests were present. The principal guests were Lord Glentoran, Minister of Commerce, and Alderman R. J. R. Harcourt, J.P., Lord Mayor of Belfast.

The President extended his visit and took the Chair at the Graduates' and Students' Evening on February 13th.

A successful social occasion in the form of a supper dance was held on March 9th. About 90 were present.

Attendance at meetings of the Association have continued to be satisfactory. The present strength is:—31 Members, 209 Associate Members, 76 Graduates, 87 Students. Colonel Robert McCreary, O.B.E., M.C., B.A., B.Sc., R.E., continued to act as the Association's representative on the Council.

## SOUTHERN ASSOCIATION

On the 13th October, 1955, Mr R. W. Hall (M), Engineer to the Portsmouth and Gosport Water Company, succeeded Mr J. W. Hunter (M) as Chairman. His address, delivered at Portsmouth, was entitled "The development of the public water supply" and dealt with progress that had been made in civil engineering aspects of water supply, with particular reference to his own experience. It was illustrated with lantern slides and the meeting was very well attended.

During the Session ten meetings have been held; two at Portsmouth, two at Brighton, three at Chichester, two at Southampton and one at Bournemouth. They covered the following subjects; geophysical methods of site exploration, mixed thermal-hydro-electric systems, the work of the Hydraulics Research Station, power station circulating water systems, stabilization with aerated cement grout and mortar and civil engineering plant management. The Dugald Clerk Lecture "Some Factors in the Design and Construction

of an Oil Refinery" was repeated to the Association by Mr H. J. W. Braddick (AM) at Chichester on the 5th January, 1956, and an unusual Paper entitled "Potentialities of the British Railways system as a reserve roadway system" was presented by Brigadier T. I. Lloyd, D.S.O., M.C., at Brighton on the 10th November, 1955, and provoked an interesting and lively discussion. The Annual General Meeting was followed by a display of civil engineering films.

Of the ten meetings held, one was joint with the Southern Centre of the Institution of Electrical Engineers, one with the Southern Branch of the Institution of Mechanical Engineers, and one with the South-Eastern District of the Institution of Municipal Engineers. Attendance at meetings, considering the exceptional weather of the last winter, has continued to be good, being an average of 85 for the Session.

In addition to the Session's ordinary meetings, the Graduates' and Students' Section has been notably active, having held three meetings; one in Portsmouth and two in Brighton. The maximum attendance at these meetings has been 75 members. The section also organized visits for Graduates and Students to take place during the summer months.

The Annual Dinner and Dance of the Association this year took place on the 11th May, 1956, at the Royal Beach Hotel, Southsea. The President, Mr W. K. Wallace, attended with the Secretary and guests included the Lord Mayor of Portsmouth, Vice-Admiral J. S. Salter, and representatives of kindred associations.

A number of visits were organized during 1955 and all were well attended. These included a cruise on Southampton Water to view the works of the Southampton Harbour Board, a visit to Langstone Bridge at Hayling Island and one to the new works at Shoreham Harbour.

Mr P. E. Sleight (M) continued to represent the Association on the Council of the Institution for the session.

## EDINBURGH AND EAST OF SCOTLAND ASSOCIATION

The Chairman for the past Session has been Mr M. C. White (M), Chief Engineer, Leith Dock Commission, who succeeded Mr Leslie H. Dickerson (M), Chief Civil Engineer, North of Scotland Hydro-Electric Board. Mr White in his inaugural address took as his subject "The engineering development of Edinburgh's coast line."

After a survey of historical events from the time of the brief occupation by the Romans of the southern coastline of the Firth of Forth, Mr White outlined the development of the Port of Leith. In 1800 John Rennie was consulted and the first engineering works of any magnitude were commenced. The introduction of the steamship in 1812 revolutionized shipping requirements and after some vicissitudes, including the establishment of a rival harbour at Granton in 1834, the Port of Leith expanded steadily. Today it has become a well-equipped seaport capable of handling large ocean-going vessels. Granton Harbour has shown a corresponding development. Mr White described the various engineering features of construction at these two ports, which are a tribute to the skill of successive generations of civil engineers.

Eleven meetings were held during the Session including two meetings for Graduates and Students and a meeting at Perth and Aberdeen respectively. In addition, an Annual Dance and the Graham Clark Lecture were held in conjunction with the Institution of Electrical Engineers. The range of subjects of the Papers at the meetings was wide and included harbour works, hydro-electric projects and "no-fines", fly-ash and reinforced concrete. The average attendance at Ordinary Meetings was about 90 compared with 85 last Session. Sir Arthur Whitaker (Vice-President) attended the meeting at Perth on 23rd March, 1956, which was very well attended.

Mr James Park (S) was awarded a commendable mention and premium for his Paper "Uplift pressures in concrete dams" in the Institution Medal Competition (Local Associations), and also a Miller Prize for Session 1954–55.

The Annual Dinner was held in November 1955 when the President, Mr W. K. Wallace, and the Secretary were welcomed by 141 members and friends.

Recent visits to engineering works included Dundee Shipyard and Harbour works; Lawers hydro-electric scheme, Killin; sewer outfall works, Kirkcaldy, and new pithead, Seafield; model of Moriston hydro-electric tail-race tunnel; Edinburgh Waterworks micro-straining plant. All visits were well attended and found interesting.

Two Christmas Lectures for Secondary School pupils were arranged by the Joint Committee on Lectures to Schools and were given under the auspices of the Institution of Municipal Engineers. Further efforts to inform Secondary School boys about Civil

Engineering were a meeting with Headmasters and Careers Masters, a Careers Exhibition in the Royal Scottish Museum and a meeting with boys and their parents arranged by the Senior Youth Employment Officer, City Education Department.

The Association continued to have the co-operation of the Heriot-Watt College, Edinburgh and the Dundee Technical College in the provision of technical library facilities for their members.

Mr W. P. Haldane (M) represented the Association on the Scottish Advisory Committee for Codes of Practice and Mr S. A. Findlay (M) on the Joint Advisory Panel on Building of the Ministry of Works. The Chairman and Honorary Secretary represented the Association on a Reception Committee of the Institution of Mechanical Engineers' Edinburgh Summer Meeting.

Two Members of the Association, viz. Mr J. L. White (M), the Association's representative, and Mr A. A. Fulton, were members of the Council for 1955–56.

## NORTH-WESTERN ASSOCIATION

The Chairman for the Session has been Mr J. D. T. Firth (M) Engineer to the Mersey River Board. In his Address delivered in Manchester on 13 October, 1955, he traced the history of land drainage legislation from the passing of the "Statute of Sewers" in 1531 to the formation of the present River Boards and outlined the many problems encountered by land drainage engineers, particularly in areas affected by mining subsidence. The Address was repeated in Liverpool on 16 November, 1955, when the opportunity was taken to express appreciation of the assistance given by Mr Firth, when Honorary Secretary, in arranging for meetings to be held in Liverpool.

Seventeen meetings, including five Joint Meetings with Local Associations of other Institutions and Engineering Societies, were held during the Session—twelve at Manchester, four at Liverpool and one at Preston. The subjects dealt with covered a wide range and included the architectural and engineering aspects of building design; the Volga-Don Canal; civil engineering aspects of atomic power generation; non-rigid types of road construction; development and uses of diving equipment; recent developments in prestressed concrete; space frames and skin structures; effects of mining subsidence; river control; soil mechanics; and public health engineering in the United States of America.

The average attendance at meetings showed a marked increase over the previous year.

The Graduates' and Students' section held a meeting in Manchester at which the topic for discussion was "The first years of professional employment". Six speakers, drawn from the different branches of civil engineering, outlined their individual experiences and many of the thirty members present contributed to the interesting discussion which followed. In June 1955, the Graduates and Students of the North Western and the Yorkshire Associations took part in a visit to Jodrell Bank, Cheshire, to see the work in progress on the construction of the new radio telescope.

Mr J. L. Kay (G), was awarded a Miller Prize for his paper on "Some aspects of airport development" and the presentation was made by the Chairman at the last Ordinary Meeting of the Session.

The second Annual Dance held in Manchester on 20 January, 1956, once more proved to be a great success and was attended by 166 members and their guests.

The Annual Dinner of the Association was held at the Midland Hotel, Manchester, on 8 March, 1956, when 140 members and their guests were present. The President and Secretary of the Institution attended, and also eminent representatives of Manchester University, Manchester College of Technology and the engineering and architectural professions of the North Western Area.

Mr J. E. Harben (M) continued to represent the Association on the Council of the Institution.

## NORTHERN COUNTIES ASSOCIATION

Mr. G. S. Short (AM), was elected Chairman of the Association for Session 1955–56 and took office in October 1955. His Chairman's Address was delivered in Newcastle, Middlesbrough and Carlisle.

During the summer and autumn of 1955 six visits were made as follows: the new deep-water berth at West Hartlepool; the instrument works of Messrs Cooke, Troughton & Simm at York; the new engraving dock at Messrs Brigham and Cowans Ltd, South Shields; Doxford Shipyard and Engineworks, Sunderland, where the party witnessed the

launch of a large oil tanker; a river trip on the Tyne to see the new Stella Power Stations; the reconstruction of Whitby Fish Quay.

The Association held 16 meetings during the Session—eight at Newcastle, six at Middlesbrough and two at Carlisle. The subjects of the Papers covered a wide field as follows: a modern coal-loading plant on the River Tyne; the roofing of Cleadon Reservoir; the construction of the Northern Section of the Haweswater Aqueduct; traffic engineering and the design and construction of Expressways, Freeways and Parkways in the United States; the design and construction of oil refineries; problems of surface development in a mining area; the development of a mechanical draught water cooling tower, and the civil engineer and Britain's atomic factories.

Dr Arthur Raistrick, well known to civil engineers in the North of England, delivered a farewell address on the occasion of his retirement from King's College, Newcastle.

Mr A. Storrar (AM) was again elected Chairman of the Graduate and Students' Section. Six meetings of the section were held, and in addition to the Chairman's Address the subjects included the construction of the Dover Car Ferry; welding failure and brittle fracture; Local Government engineering; and pollution of the River Tyne.

Good attendance at visits and meetings have been maintained.

Again a Dinner and Dance was held at Durham Castle in January and though as usual, weather conditions made travelling difficult, about 160 members and ladies attended and spent an enjoyable evening.

For the first time in the history of the Association, and in deference to Members residing on Tee-side, the Annual Dinner of the Association was this year held at West Hartlepool, on 23rd March. The President and Secretary of the Institution were present at the dinner and some 92 members and their guests spent an enjoyable evening.

## YORKSHIRE ASSOCIATION

The 1955–56 Session opened on 30 September, 1955, when the new Chairman, Lt-Col. S. Maynard Lovell, O.B.E., T.D. (AM), Engineer and Surveyor, West Riding County Council, as successor to Mr J. G. Taylor (M), delivered his Address at a meeting held in Leeds. The Address was repeated at Hull on 18 October, 1955.

During the Session, a total of eight Ordinary Meetings have been held: one meeting in Scunthorpe, one in York, three in Leeds and three in Sheffield. The meeting in Scunthorpe was held jointly with the local branch of the Lincolnshire Iron and Steel Institute and the Yorkshire Branch of the Institution of Structural Engineers. In addition, one other meeting was held jointly with the Yorkshire Branch of the Institution of Structural Engineers.

Subjects covered by the papers were the railway modernization and re-equipment plan; a prestressed concrete dam; brittle fracture in steel; planning of ring roads and the construction of Aden oil harbour. In addition, a visit was made to the steelworks of Messrs Steel, Peach and Tozer.

The average attendance at Association meetings was about 50.

The Association has been represented on the Council by Mr J. G. Taylor, C.B.E. (M), Divisional Road Engineer, N.E. Division, Ministry of Transport and Civil Aviation.

Three meetings of the Graduates' and Students' Section have been held in addition to the Annual General Meeting and a visit to a lime and cement works held jointly with the Junior Section of the Yorkshire District of the Institution of Municipal Engineers. A successful dance organized by the Graduates' and Students' Sections of the Institutions of Civil, Mechanical and Electrical Engineers was held on 9 December, 1955.

The Annual Dinner Dance of the Association was held on 7 March, 1956, at the Queens Hotel, Leeds, and was attended by 136 guests, members and their friends. The President and Secretary of the Institution, together with Mrs Wallace and Mrs McDonald were present, and the other guests included the Lord Mayor and Lady Mayoress of Leeds and the Presidents and Chairmen of kindred Societies and their ladies. Although ladies have been present at the Annual Dinners for some years, this is the first occasion on which the Association has held a Dinner Dance. There was every indication that the evening was enjoyed by all present.

The Hull and East Riding Branch of the Association held six meetings, all in Hull, during the Session.

At the opening meeting on 18 October, Mr T. H. Jones (M), Water Engineer and Manager, Hull, who took a prominent part in the inauguration of the Branch and had been its Chairman or Acting Chairman from the beginning, handed over the Chairmanship to Mr W. Morris (M), City Engineer and Surveyor, Hull, after which Mr S. M. Lovell (AM),

the Yorkshire Association Chairman, repeated his Address. The two entrants in the competition for the Branch Chairman's prize for Graduates' and Students' papers presented their papers at one of the meetings. The prize was awarded to Mr P. Gould (G), for his paper on syphon spillways, a subsidiary prize being awarded to Mr H. C. Wilson (S) for his paper on tunnel surveying. One meeting was held jointly with the Yorkshire Branch of the Institution of Structural Engineers. Subjects covered at other meetings were technological education, a dock failure and repair, dock and harbour structures and large-diameter sewers in tunnel. Most of the papers were by local authors. The average attendance was about 51.

In December 1955 the Branch held a successful informal dinner followed by dancing and party games, attended by 91 members, guests and their ladies.

An all-day visit to works in progress in Hull and district and a social outing in July, were also held.

Close contact with the Hull College of Technology has continued to be maintained by a Sub-Committee of the Branch.

## SOUTH WALES AND MONMOUTHSHIRE ASSOCIATION

Lt-Col. Arthur Borlase, T.D. (M) was elected Chairman of the Association in succession to Mr A. V. M. Bell (M) and took office on 5 October, 1955. He delivered an address entitled "Civil engineering under the New Towns Act, 1946" in which he drew upon his experience during the past five years as Chief Engineer to the New Town Development Corporation at Cwmbran.

During the session, eight ordinary meetings have been held—six at Cardiff and two at Swansea—of which two have been held jointly with the Institution of Municipal Engineers and one with the Institution of Structural Engineers. The lectures delivered at these meetings covered the uses of aerated cement grout; clay as a foundation material; prestressed concrete building frames; bridge loading; sewer design; plate girder research; pedestrian crossings; and municipal and roadworks. The average attendance at these meetings was 53.

A visit to the Neath By-pass bridge attracted an attendance of 95, and visits were also made to a waterworks reservoir and pumping station and to an open-cast coal site.

At Cardiff on 6 January, 1956, the Association received a Vice-Presidential visit by Professor A. J. S. Pippard in what is hoped will become a regular feature of each Session's programme.

The fifth Annual Ball was again organized at Porthcawl by the Graduates' and Students' Section and provided the enjoyment that is now regarded as normal for this function.

The Annual Dinner at the Royal Hotel, Cardiff, on 16 March, 1956, proved to be a great success. The President Mr W. K. Wallace, was present together with the Secretary of the Institution, Mr Alexander McDonald, and 115 members and guests. After the toasts, the Chairman, on behalf of former fellow-members of the Committee, presented Mr T. Leslie Lowe (M) with a pair of tankards in appreciation of the four years' service which Mr Lowe had given the Association as Honorary Secretary.

Lt-Col. Borlase was re-elected Council Member for a second Session, and Mr E. C. Roberts (M) represented the Association on the Ministry of Works Regional Advisory Committee.

The Session members of the Association gave talks to a meeting of Youth Employment Officers and Careers Masters of Glamorganshire at Cardiff and to Schools in Swansea.

The Committee has met on ten occasions and the average attendance has been 14.

# APPENDIX IV

## Deaths and Resignations

The full list of deaths is as follows (E. refers to election, T. to transfer, and A. to admission):—

*Members* (78).—Charles Antony Ablett, *O.B.E.*, B.Sc.(Eng.) (E. 1907, T. 1919); *Sir* Athol Lancelot Anderson, *K.C.B.* (*former Member of Council*) (E. 1900, T. 1913); David Grant Anderson, B.Sc. (E. 1921, T. 1943); Alfred Henry Aslett (E. 1892, T. 1920); John Dekeyne Atkinson, B.A. (E. 1922, T. 1935); *Lt-Col.* Graham Townsend Bennett, *O.B.E.*, B.Sc. (*former Member of Council*) (E. 1922, T. 1945); Alfred Thomas Best (E. 1904, T. 1931); Maurice George Bland, *O.B.E.* (E. 1910, T. 1932); William Ewart Blizard, B.Sc.(Eng.)

(E. 1916, T. 1929); John Edward Bostock, *O.B.E.* (E. 1904, T. 1916); *Lt-Col.* John Aldhelm Raikes Bromage, *C.I.E.* (E. 1917, T. 1933); Theobald Stuart Butler (E. 1910, T. 1926); Robert Archibald Campbell, B.Sc. (E. 1912, T. 1946); William Eames Caton (E. 1927); Wilfrid Dinsey Chapman, M.C.E. (E. 1932, T. 1941); William Henry Clark (E. 1925); George Rudd Collinson, B.Sc.(Eng.) (E. 1911, T. 1922); Philip Grosvenor Corin, M.A. (E. 1932, T. 1936); Eustace Herbert Cornelius (E. 1925); Alfred Douglas Creer (E. 1905, T. 1919); Frederic William Duckham (E. 1903, T. 1911); Edward Thomas Frederick Elbury, B.Sc. (E. 1935, T. 1949); Gordon Rattray Fenton, *O.B.E.* (E. 1926, T. 1942); Ernest Hone Ford, *O.B.E.* (E. 1911, T. 1931); John Wishart Fairlie Gardner (E. 1894, T. 1905); Eric John Lawson Gibson, B.A. (E. 1919, T. 1941); Arthur Graham Glasgow (E. 1898, T. 1898); Thomas Morton Gourlay (E. 1919, T. 1943); James Percy Hallam (E. 1942); Philip Hammond (E. 1891, T. 1920); Robert William Leslie Harris, B.Sc. (E. 1942, T. 1945); Sydney Thomas Edward Heaton-Ellis (E. 1893, T. 1908); Richard Joseph Howley, *C.B.E.* (E. 1897, T. 1912); Frank Walton Jameson (E. 1924); *Sir* John Robert Kemp, M.E. (E. 1929); Claude George Kent (E. 1909, T. 1933); William Hubert Kirby, *M.C.* (E. 1911, T. 1939); John Henry Wales Laverick (E. 1924); William Lowe Lowe-Brown, D.Eng., M.Sc. (E. 1902, T. 1910); Robert Cowan Macdonald (E. 1933); Gustave Paul Robert Magnel (E. 1950); Frederick Robert Melville, B.Sc. (E. 1912, T. 1930); *Sir* (Frederick Leighton) Victor Mills, *Bt.* (E. 1934, T. 1944); Ernest Minors, *O.B.E.*, B.Sc.(Eng.) (E. 1907, T. 1946); George Porteous Mitchell (E. 1932); Donald Moir (E. 1935); Ernest Edward Morgan (E. 1935); Stefan Georg Munz (E. 1948, T. 1950); Robert Stribley Murt, *O.B.E.* (E. 1920, T. 1932); John Orr, *O.B.E.*, LL.D., B.Sc. (E. 1904, T. 1910); Frederick Gaston Penny (E. 1915, T. 1942); Eustace William Porter, *M.B.E.* (E. 1899, T. 1922); William Ransom (E. 1905, T. 1922); *Sir* Richard Augustine Studdert Redmayne, *K.C.B.*, M.Sc. (E. 1908); Bernard Alexander Rice, B.A., B.A.I. (E. 1929, T. 1946); Frederick Sanderson Robins (E. 1894, T. 1919); Henry Knight Rodgers (E. 1929, T. 1939); John Mawson Rounthwaite, B.Sc. (E. 1909, T. 1939); James Leishman Roy (E. 1918, T. 1944); Charles Herbert Rutter (E. 1894, T. 1913); Thomas Henderson Scott, *O.B.E.* (E. 1915, T. 1924); William Herbert Shields, B.Sc. (E. 1897, T. 1923); Frank Walter Shilstone (E. 1921, T. 1938); Harry Watson Smith, *C.B.E.* (E. 1942); Percy Starkey Spencer (E. 1911, T. 1929); *Major General Sir* Clive Selwyn Steele, *K.B.E.*, *D.S.O.*, *M.C.*, *V.D.*, B.C.E. (E. 1918, T. 1927); William Storrie (E. 1909, T. 1929); George Stow, *O.B.E.* (E. 1901, T. 1953); Arthur Ayton Symington, B.Sc.(Eng.) (E. 1928, T. 1941); Philip Howard Thorne, *M.C.* (E. 1920, T. 1928); Albert Tulip, M.Sc. (E. 1928); James Cecil Lionel Verley (E. 1905, T. 1920); Donald Murray Walker, M.Eng. (E. 1929, T. 1950); Harold Whipp, *O.B.E.*, B.Sc. (E. 1928, T. 1948); John Sigismund Wilson (E. 1903, T. 1927); Ernest Worrall (E. 1921); Harry Edward Yerbury, *M.B.E.* (E. 1909); *Sir* Cyril Roe Muston Young, *Bart.* (E. 1912, T. 1929).

*Associate Members* (90).—Ian Evelyn Allanson, M.A. (E. 1951); George Samuel Elam Barker (E. 1924); William Douglas Barraclough (E. 1918); John Philip Bett (E. 1933); Robert Blackburn, *O.B.E.* (E. 1913); Charles Godfrey Boyton, M.A. (E. 1944); Francis Thomas Hilton Bradley, B.E. (E. 1948); George Gladman Braid (E. 1900); Harry Bertram Edwin Brown (E. 1910); Norman Buckley (E. 1947); James Burdon (E. 1939); James Denys Bush, B.Sc. (E. 1925); *Major* Douglas Marshall Cannon, *M.B.E.*, R.E.M.E. (E. 1932); William Eric Crosby Clark (E. 1944); Arthur Henry Clarke, B.Sc. (E. 1936); William Clifford (E. 1906); James Cruikshank (E. 1925); John Frederick Cubbon, *D.S.O.*, *M.C.* (E. 1942); Rupert Nelson Dearham (E. 1945); Albert Edward Dicks (E. 1910); John Bertram Donat, B.Sc.(Eng.) (E. 1950); Gerald Stephen Dunkin, B.Sc.(Eng.) (E. 1925); Ian Cecil Easton, B.Sc. (E. 1933); Leonard Julius Elgin (E. 1945); Edward Arthur Evans, B.Sc. (E. 1910); Walter Paul Frederick Fanghaenel, B.Sc.(Eng.) (E. 1915); Philip Cyril Egbert Fields-Clarke (E. 1920); Reginald Tom Fitzpatrick, B.Sc. (E. 1928); Henry Walter Ford (E. 1883); John Richard Stratford Fox (E. 1893); David Johnson Gadsby (E. 1900); Wilfrid Harry Gamble (E. 1930); Charles Douglas Gee (E. 1907); Robert Gilchrist (E. 1908); Arthur Stanley Glover, *M.C.*, B.Sc. (E. 1918); Charles Leavers Hall, B.Sc.(Eng.) (E. 1918); Peter Bryan Harding, B.Sc. (E. 1946); Edward Henry Harrison (E. 1889); Russell Taylor Haworth (E. 1952); Percy Stewart Heaselden (E. 1920); Frederick George Helsby (E. 1910); Francis Bovill Higgins (E. 1896); Jack Holt (E. 1928); William MacLean Homan (E. 1896); Leonard Thomas Horton, B.Eng. (E. 1934); Ronald Alexander Inglis, B.Sc.(Eng.) (E. 1915); Edwyn Jervoise (E. 1911); Herbert Malcolm Jordan (E. 1919); *W/Cdr.* Leonard Nevill King, B.Sc.(Eng.) (E. 1936); Leonard Lacey, B.Sc.(Eng.) (E. 1920); William Faulkner Lowe, *M.C.*, M.Eng. (E. 1934); Sydney William Luscher (E. 1919); Andrew Howie McBride, B.Sc. (E. 1928); Alexander Simpson Macdonald, B.Sc. (E. 1921); Thomas James McDonald (E. 1904); Ernest Arthur McGill, *O.B.E.*, M.Sc. (E. 1919); Howard Martineau (E. 1890); John Halliwell Mawson, *M.C.*, B.Sc. (E. 1914); William Henry Maxwell (E. 1900); Cecil

Edward Mays (E. 1919); Sidney Thomas Monté (E. 1931); James Moore (E. 1906); Richard Douglas Morris, B.Sc.(Eng.) (E. 1914); Charles Franklin Murphy (E. 1902); Thomas Albert Neill (E. 1904); Edward Ambrose Oliver (E. 1934); Sydney Elliott Page (E. 1894); Arthur David Clere Parsons, B.A. (E. 1909); Ernest Lancelot Pledger (E. 1910); Walter Reeve (E. 1906); Ernest Alfred Rex (E. 1924); Stanley Lewis Richards (E. 1918); Henry Ernest Robarts (E. 1906); Alfred John Adams Roseveare, B.Sc.(Eng.) (E. 1945); Harry Lionel Sargent (E. 1895); Anthony Bean Saunders-Jacobs, B.Sc.(Eng.) (E. 1929); James Henry Segrave (E. 1909); Thomas Reginald Sewell, *M.C.*, B.Sc. (E. 1911); Ewart Renton Shackleton (E. 1942); Cyril Graham Smith, *O.B.E.* (E. 1910); Percy Francis Spiller (E. 1916); Walter Perchard Stericker (E. 1897); Hubert Royds Tidswell, B.Sc.(Eng.) (E. 1911); Albert Edward Valler (E. 1937); David Bowe Waters, B.Sc. (E. 1939); Charles Marcus Allen Whitehouse (E. 1910); Arthur Lee Whitwam, B.A. (E. 1940); Percy Wilkinson (E. 1909); Robert Alfred Wilkinson (E. 1879); Harben Robert Young (E. 1910).

*Graduates* (5).—Thanuvelil Koshy George, M.Sc. Tech. (A. 1952); Gordon Derek Hill (A. 1952); Eric Hedley Kerry, B.Sc. (A. 1952); Robert Peter Melson, B.Sc.(Eng.) (A. 1952); Gordon Douglas Sharpe, B.Sc.(Eng.) (A. 1953).

*Students* (2).—Neil Cameron Mackintosh (A. 1955); Michael Oliver Rogers (A. 1947).

The following resignations have been received:—

*Members* (10).—Frederic Harold Roberts Came, *M.B.E.* (E. 1925, T. 1947); John Chisholm (E. 1916); John Henry Woulfe Flanagan (E. 1911, T. 1930); Fred Berry Greenwood, *O.B.E.* (E. 1908, T. 1928); Harry Broughton Hurst (E. 1912, T. 1934); Walter MacLachlan, B.E. (E. 1919, T. 1926); Arthur Winfield Nightingale (E. 1938, T. 1938); John Lucian Savage (E. 1940); Francis Hubert Seabrooke (E. 1926, T. 1937); Sir (Thomas) Eric (Boswell) Young (E. 1944).

*Associate Members* (49).—Harold William Ashby (E. 1916); Reginald Charles Atkinson (E. 1910); Charles George Baker (E. 1919); Frank Bates (E. 1910); John Victor Bessant (E. 1918); *Brigadier* Charles Mendelssohn Bostock (E. 1917); Talbot Cottom Broom (E. 1907); Clifford Charles Champeney (E. 1911); William John Connolley, B.Sc. (E. 1923); George Malcolm Cruickshank, M.A. (E. 1916); Valentine Edmund Douglas, B.E. (E. 1935); Alexander Butchart Duncan (E. 1933); Raymond Faucit Wilmot Eardley (E. 1918); Hugh Eastman (E. 1925); William Eccles, M.Sc. (E. 1912); *Rao Bahadur* Dwarkanath Atmaram Gadkary, B.E. (E. 1933); Fred Albert Gerrard (E. 1919); Ronald Gordon Gillean (E. 1929); Wilfrid Granger (E. 1919); Kenrick Denis Durley Grazebrook (E. 1913); Leslie Kirk Greene, B.Sc. (E. 1924); Arthur Illtyd Jenkins, B.Sc.(Eng.) (E. 1923); Dudley Vincent Joyce (E. 1915); *Professor* Leslie James Kastner, M.A., M.Sc. (E. 1941); Richard Kendall (E. 1916); Oscar Le Maistre Knight, B.E. (E. 1924); William Maximilian Lindley, *M.C.*, M.A. (E. 1918); Harry Chickall Lott, *M.C.* (E. 1909); Fergus Malcolm Graeme McConechy, *O.B.E.*, B.Sc. (E. 1917); Charles William Macfie, B.Sc. (E. 1915); Robert McIntrye (E. 1927); Eric Mallinson, B.Sc. (E. 1918); Jack Matthews (E. 1929); Leonard Challinor Miller, *D.S.O.*, B.Sc.(Eng.) (E. 1919); Frederick Oldham Mills (E. 1909); Kenneth Barclay Milne, B.Sc.(Eng.) (E. 1917); Charles Vincent Moodie (E. 1916); Norman Moore, B.Sc. (E. 1926); Frederick Knox Ouseley Moynan (E. 1918); *Sir* Christopher Norman Musgrave, *Bart.*, B.A., B.A.I. (E. 1924); Francis Edward Oakes (E. 1912); Victor Charles Walton Rapson, B.E. (E. 1932); Frank Arthur Shorter (E. 1926); Alwyn Eckette Simpson (E. 1921); Henry Ernest Stratton (E. 1910); Hugh Terrell (E. 1910); Francis Henry Walker (E. 1910); Joseph Watson (E. 1922); Alfred Evans Wheatley (E. 1912).

*Graduates* (9).—Philip Holden Bond, B.A. (A. 1953); Thomas Grandin Chapman, B.Sc. (A. 1953); Lawrence Allan Colbert, B.Sc. (Eng.) (A. 1955); Peter John Fretter (A. 1953); Joel David Harold Gamse, B.Sc. (Eng.) (A. 1953); Neil Jackson, B.Sc. (A. 1952); John David Campbell Macleod, B.Sc. (A. 1954); Michael John Morgan, B.Sc.(Eng.) (A. 1952); Michael Rex Marriott Tetley, *M.B.E.*, B.Sc. (A. 1952).

*Students* (43).—Thomas Addison (A. 1953); John Michael Alcock (A. 1950); Jack Andrews (A. 1953); John Shaw Aspinall (A. 1951); Anthony Patrick Athawes (A. 1952); David Barclay (A. 1952); Arnold John Bennett (A. 1951); Richard Farran Breakell (A. 1954); Alec Thomas Brown, B.Eng. (A. 1951); Makhan Lal Chodri (A. 1954); John Charles Cooper (A. 1949); Keith Donaldson (A. 1946); Dennis Kenneth Eldridge (A. 1948); Edgar Roy England, M.Sc.(Eng.) (A. 1946); Brian Herbert Walsh Griffin (A. 1947); Francis Joseph Grimer (A. 1953); Robert Mervyn Hearst (A. 1952); Brian George Heasman (A. 1953); Peter John Holdcroft (A. 1951); Roy Holdman (A. 1951); Robin Eckersley James (A. 1950); Susanta Chandra Lahiri (A. 1951); Victor Brian Lang (A. 1953); Barry James Large (A. 1950); Frederick Keith Lloyd (A. 1950); Douglas Mackenzie Nelson (A. 1947); George

Michael Nesteroff (A. 1950); Edmund Anthony Peel (A. 1954); Michael James Phillips (A. 1953); Vernon Frederick Price (A. 1952); Colin James Rainsford-Moore (A. 1952); James Purves Fraser Redden (A. 1953); Patrick David Roberts (A. 1954); Albert Kenneth Saint (A. 1947); Ralph Sanderson (A. 1949); Fraser Kennedy Smith (A. 1954); Jack Sutton, B.Sc.(Eng.) (A. 1947); Arnold Thomas (A. 1950); Myrddin Pryce Thomas (A. 1951); Peter Beel Watson (A. 1949); Graham West (A. 1951); Christopher Wiley (A. 1952); Harold Willits (A. 1953).

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# THE INSTITUTION

## BALANCE SHEET

| 31 March 1955 £ | | | £ s. d. | £ s. d. |
|---|---|---|---|---|
| | **INSTITUTION CAPITAL ACCOUNT** | | | |
| 414,759 | *As per last Account* . . . . . . . . . . . | | | 414,758 16 10 |
| | **INSTITUTION BUILDING SINKING FUND** | | | |
| | *As per last Account* . . . . . . . . . . | | 2,984 18 10 | |
| | Add : Allocation for year to date . . . . . . | | 450 0 0 | |
| | Interest on Investments and Income Tax refunded . . . . . . . . . | | 110 8 1 | |
| 2,985 | | | | 3,545 6 11 |
| | **REPAIRS AND RENEWALS RESERVE** | | | |
| 2,463 | *As detailed on page 466* . . . . . . . . | | | 4,179 16 1 |
| | **GENERAL REVENUE ACCOUNT SURPLUS** | | | |
| | Balance at 31st March, 1955 . . . . . . . | | 35,102 12 3 | |
| | Less : Deficit for the year to date, *page 467* . . | | 7,396 4 2 | |
| 35,103 | | | | 27,706 8 1 |
| 455,310 | | | | 450,190 7 11 |
| | **CREDITORS—** | | | |
| 21,833 | Sundry Creditors . . . . . . . . . . | | | 17,700 18 11 |
| | **REVENUE IN SUSPENSE** | | | |
| 46,369 | Proportion of subscriptions, examination fees, etc. received relating to the period after 31st March, 1956 . . . . . . . . . . . . . . | | | 49,887 7 5 |
| 523,512 | | | | 517,778 14 3 |
| | **TRUST FUNDS** | | | |
| | Capital Accounts . . . . . . . . . . . . | | 69,779 4 0 | |
| | Unexpended Income— | | | |
| | Balance per last account . . . | 9,259 13 0 | | |
| | Add : Income received for the year to date . . . . . . | 2,330 1 9 | | |
| | | 11,589 14 9 | | |
| | Less : Expenditure on Scholarships, Prizes, Lectures, etc. . | 1,555 8 11 | | |
| | | | 10,034 5 10 | |
| 78,864 | | | | 79,813 9 10 |
| | **SEA ACTION COMMITTEE ACCOUNT—** | | | |
| | Balance at 31st March, 1955 . . . . . . . | | 1,031 19 1 | |
| | Less: Payments for the year to date . | 86 1 0 | | |
| | Less : Interest and other receipts for the year to date . . . . . . . | 38 0 11 | | |
| | | | 48 0 1 | |
| 1,032 | | | | 983 19 0 |
| £603,408 | | | | £598,576 3 1 |

*REPORT OF THE AUDITORS TO THE MEM*

We have obtained all the information and explanations which to the best of our knowled kept by the Institution so far as appears from our examination of those books. We have exa of account. In our opinions and to the best of our information and according to the explan 31st March, 1956, and the General Revenue Account gives a true and fair view of the deficit f

*London, 10th May, 1950*

L ENGINEERS

ST MARCH, 1956

| March 1955 £ | | | £ s. d. | £ s. d. |
|---|---|---|---|---|
| | **FREEHOLD PROPERTY—INSTITUTION BUILDING—** | | | |
| 75,768 | *At cost, as per last Account* . . . . . . . . | | .. | 375,767 16 10 |
| | **INSTITUTION INVESTMENTS** at or | | | |
| 85,878 | under cost . . . . . . . . . . . . . | | .. | 85,745 3 10 |
| | *Market value*, £68,503—(1955, £78,543) | | | |
| | **INSTITUTION BUILDING SINKING FUND** | | | |
| 2,896 | Investments at cost . . . . . . . . . . | | 3,434 18 10 | |
| | *Market Value*, £2,758—(1955, £2,687) | | | |
| 89 | Cash awaiting investment . . . . . . . . | | 110 8 1 | |
| | | | | 3,545 6 11 |
| 4,365 | **DEBTORS** . . . . . . . . . . . | | | 5,943 8 8 |
| 54,516 | **BALANCES AT BANKERS AND CASH IN HAND** | | | 46,776 18 0 |
| 23,512 | | | | 517,778 14 3 |
| | **TRUST FUND ASSETS—** | | | |
| | Capital :— | | | |
| | Investments . . . . . . . | 69,748 4 3 | | |
| | *Market value*, £49,062—(1955, £57,376) | | | |
| | Balance at Bankers . . . . . | 30 19 9 | | |
| | | | 69,779 4 0 | |
| | Unexpended Income— | | | |
| | Investments . . . . . . . | 437 0 11 | | |
| | *Market value*, £300—(1955, £352) | | | |
| | Balance at Bankers . . . . . | 9,597 4 11 | | |
| | | | 10,034 5 10 | |
| 78,864 | | | | 79,813 9 10 |
| | **SEA ACTION COMMITTEE ACCOUNT—** | | | |
| | £700 3% Savings Bonds 1955/65 at cost . . . | | 700 0 0 | |
| | *Market value* £592—(1955, £668) | | | |
| | Balance at Bankers . . . . . . . . . . | | 283 19 0 | |
| 1,032 | | | | 983 19 0 |
| 03,408 | | | | £598,576 3 1 |

A. McDONALD, *Secretary*

*E INSTITUTION OF CIVIL ENGINEERS.*

ere necessary for the purposes of our audit. In our opinions proper books of account have been
ve Balance Sheet and annexed General Revenue Account which are in agreement with the books
the said Balance Sheet gives a true and fair view of the state of the Institution's affairs at the
ded on that date.

A. RAE SMITH }
J. A. JOHNSTON } AUDITORS.

# RESERVE FOR REPAIRS AND RENEWALS TO STRUCTURE, FURNITURE, FITTINGS AND MACHINERY

| 1954–55 £ | | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| *3,746* | BALANCE, per last account | | | | 2,463 | 9 | 7 |
| | Add CREDITS during the year— | | | | | | |
| *250* | Allocation from Interest on Investments | | | | 250 | 0 | 0 |
| | Institution Revenue Account— | | | | | | |
| *4,000* | Amount provided for the year, *page 467* | | | | 4,000 | 0 | 0 |
| *7,996* | | | | | 6,713 | 9 | 7 |
| *5,533* | Less NET EXPENDITURE during the year | | | | 2,533 | 13 | 6 |
| *2,463* | BALANCE carried forward, per Balance Sheet, *page 464* | | | | 4,179 | 16 | 1 |

## PUBLICATIONS EXPENDITURE

| | | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| | EXPENDITURE during the year— | | | | | | |
| *26,412* | Proceedings, etc. | | | | 29,411 | 13 | [illegible] |
| *2,148* | "Chartered Civil Engineer" | | | | 2,848 | 7 | [illegible] |
| *53* | Charters, By-laws and Lists of Members | | | | 1,194 | 18 | [illegible] |
| *732* | Engineering Abstracts | | | | 789 | 1 | [illegible] |
| *7,524* | Salaries, Pension Premiums and National Insurance | | | | 9,574 | 19 | [illegible] |
| *485* | Reporting and Sundries | | | | 585 | 15 | [illegible] |
| — | "Géotechnique"—Expenses less Receipts | | | | 886 | 12 | [illegible] |
| *37,354* | | | | | 45,291 | 8 | [illegible] |
| | Deduct:— | | | | | | |
| | Credits for Advertisements, | | | | | | |
| *18,445* | Sales, Subscriptions, etc. | 21,562 | 12 | 6 | | | |
| *213* | "Géotechnique"—Receipts less Expenses | — | — | — | | | |
| *18,658* | | | | | 21,562 | 12 | [illegible] |
| *18,696* | Net Expenditure per General Revenue Account, *page 467* | | | | 23,728 | 15 | [illegible] |

## RESEARCH EXPENDITURE

| | | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| | EXPENDITURE during the year— | | | | | | |
| *1,503* | Salaries, Pension Premiums and National Insurance | 1,640 | 2 | 6 | | | |
| *32* | Travelling to Committees, etc. | 35 | 7 | 10 | | | |
| *597* | Printing of Sundry Reports | 643 | 14 | 1 | | | |
| *58* | Sundry Expenses | — | — | — | | | |
| *2,190* | | | | | 2,319 | 4 | [illegible] |
| *2,789* | SALES of Proceedings and Reports | | | | 1,324 | 13 | [illegible] |
| Surplus *599* | Net Expenditure per General Revenue Account, *page 467* | | | | 994 | 10 | [illegible] |

# GENERAL REVENUE ACCOUNT FOR THE YEAR ENDED 31st MARCH, 1956

## INCOME.

| 1954–55 £ | | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| 71,469 | Subscriptions received applicable to the financial year 1955–56 | .. | | | 77,035 | 18 | 8 |
| 10,035 | Entrance Fees | .. | | | 10,309 | 14 | 5 |
| — | Life Composition | .. | | | 125 | 0 | 0 |
| | Interest, Dividends, etc.— | | | | | | |
| | On Institution Investments | 2,199 | 2 | 4 | | | |
| | On Deposit Account | 608 | 17 | 8 | | | |
| 2,787 | Income Tax recovered for the year 1954–55 | 414 | 9 | 9 | 3,222 | 9 | 9 |
| 10,237 | Examination Fees for the April and October 1955 Examinations | .. | | | 11,819 | 11 | 6 |
| 264 | Higher National Certificates—receipts less expenses | .. | | | 262 | 18 | 7 |
| 1,913 | Library Fund Donations | .. | | | 1,350 | 9 | 9 |
| 599 | Research—*see page 466* | .. | | | — | — | — |
| 2,324 | Sales of Reports, etc. | .. | | | 3,161 | 1 | 8 |
| 99,628 | TOTAL INCOME | .. | | | 107,287 | 4 | 4 |

## *Deduct* EXPENDITURE.

| 1954–55 £ | | £ | s. | d. | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|---|---|---|
| 15,848 | House and Establishment Charges | | | | 17,342 | 13 | 5 | | | |
| | Repairs and Renewals Reserve— | | | | | | | | | |
| 4,000 | Amount provided for the year, *page 466* | | | | 4,000 | 0 | 0 | | | |
| 20,667 | Salaries and Wages (including staff pension premiums and National Insurance) | | | | 26,879 | 2 | 11 | | | |
| 6,313 | Stationery, Printing, Postage, etc. | | | | 8,951 | 9 | 9 | | | |
| 18,696 | Publications—*see page 466* | | | | 23,728 | 15 | 6 | | | |
| — | Research— „ „ „ | | | | 994 | 10 | 9 | | | |
| 4,733 | Library | | | | 5,781 | 14 | 5 | | | |
| 8,772 | Examination Expenses | | | | 12,317 | 10 | 6 | | | |
| | Grants and Contributions— | £ | s. | d. | | | | | | |
| | Local Associations and Overseas Groups | 5,717 | 10 | 7 | | | | | | |
| | Overseas Advisory Committees | 19 | 7 | 2 | | | | | | |
| | Other Bodies | 153 | 8 | 1 | | | | | | |
| 5,271 | | | | | 5,890 | 5 | 10 | | | |
| 144 | Annual Dinner | | | | 176 | 12 | 7 | | | |
| 1,731 | Conversaziones | | | | 1,716 | 19 | 2 | | | |
| 830 | Legal and other Professional Charges | | | | 2,087 | 12 | 10 | | | |
| 788 | Public Relations Committee Expenses | | | | 652 | 11 | 7 | | | |
| 1,456 | Engineering Conferences | | | | 1,640 | 4 | 6 | | | |
| 1,378 | Travelling Expenses to Committees | | | | 1,636 | 13 | 4 | | | |
| 345 | Other Expenses | | | | 436 | 11 | 5 | | | |
| 450 | Institution Building—Sinking Fund Allocation | | | | 450 | 0 | 0 | | | |
| 91,422 | TOTAL EXPENDITURE | | | | | | | 114,683 | 8 | 6 |
| Surplus 8,206 | Balance, being Deficit for the Year carried to Balance Sheet | | | | | | | £7,396 | 4 | 2 |

# OBITUARY

WILLIAM EWART BLIZARD, B.Sc.(Eng.), who was born on 9 June, 1889, died on 15 January, 1956.

He was educated at King's College School, Wimbledon, and at the University of Southampton.

He commenced his professional career with Messrs Lemon and Blizard, Consulting Engineers, of Westminster. In 1912 he entered the Indian Service of Engineers, and was employed on the design and construction of the Gangao Dam, the Mirzapore Canal Project, and on the Sarda Canal Project as Executive Engineer, and other large irrigation works.

During the 1914–18 war he held a commission in the Indian Army and served with a field company of the Queen's Own Sappers and Miners in Iraq and Persia.

In 1920 he returned to the Indian Service of Engineers and was engaged on the design and construction of bridges, canals, and barrages. For a number of years, until the time of his death, he was a senior Partner in the firm of Messrs Lemon and Blizard, and as Consulting Engineer was responsible for the design and construction of many works of water supply and sewage disposal for Local Authorities in the United Kingdom.

He served in the Engineering and Railway Staff Corps, Royal Engineers (Territorial Army) and at the time of his death he held the rank of Lieutenant-Colonel. During the 1939–45 war he worked with the Ministry of Health as Regional Engineer in the South-West Region and became Deputy Chief Engineer, Ministry of Home Security.

He was elected an Associate Member in 1916, and was transferred to the class of Members in 1929. He was also a Member of the Institution of Water Engineers, a Past-President of the Institution of Sanitary Engineers, a Member of the Royal Sanitary Institute, and a Member of the Association of Consulting Engineers.

He is survived by two daughters.

PHILIP GROSVENOR CORIN, M.A. (Cantab.), who was born on 14 August, 1897, died on 14 October, 1955.

He was educated at Shebbear College, North Devon, from 1907 to 1914, and in 1919 he entered Christ's College, Cambridge, where he read the Mechanical Sciences Tripos. He graduated in 1922.

From 1915 to 1918 he served with the anti-aircraft artillery of the British Expeditionary Force in France, and had an opportunity for experimental work on gunsights and automatic hydraulically operated gun-laying gears. When discharged in 1918, he was a flight cadet with the Royal Flying Corps.

In 1922, he was appointed Construction Engineer on the staff of Imperial Chemical Industries at Billingham and supervised the erection of industrial boilers. He later designed and installed gas purification and synthesis plants, and was engaged on process units and as Research Group Manager, on the hydrogenation of coal. He was appointed Deputy Works Manager in 1932, in control of shops, and was responsible for the design of many new pieces of plant. From 1934 to 1935 he was Plastics Group Engineer.

He became Vice-Chairman and Technical Director of Henry Berry & Co., Ltd in 1935. In this capacity he was first concerned with high-pressure hydraulic equipment, railway workshop tools, and chemical plant. After 1939 he was engaged on the development of machines to produce recoil systems for tank and anti-tank guns, and the design of other hydraulic equipment and apparatus in connexion with torpedo and gunnery work. From 1952 until his death he was Joint Managing Director of the firm.

He was elected an Associate Member in 1932, and was transferred to the class of Members in 1936. He was a Member of the Institute of Welding and of the American Society of Mechanical Engineers.

He is survived by his wife, a daughter, and a son.

EDWARD ARTHUR EVANS, B.Sc., who was born in 1886, died in June 1955.

He graduated from the University of Wales, and became Assistant to the County Surveyor (Roads and Bridges) of Caernarvonshire, as well as practising as a Civil Engineer and Surveyor in a private capacity. He deputized as County Surveyor in 1914 and, on the outbreak of war, was mobilized with the Special Reserve of Officers, Royal Engineers. He lost his right leg from wounds sustained in action in October 1914, and was invalided out of the Army in March 1918, with the rank of Captain. In the same year, 1918, he was appointed County Surveyor (Roads, Bridges, and County Buildings) of Montgomeryshire.

In 1926, he was appointed County Surveyor (Roads and Bridges) of Denbighshire, and held that office until 8 August, 1950.

He was elected an Associate Member in 1910. He was also a Fellow of the Royal Institution of Chartered Surveyors, and a Member of the Institution of Municipal and County Engineers.

He is survived by his wife.

SIR RICHARD AUGUSTINE STUDDERT REDMAYNE, K.C.B., M.Sc., who was born at Low Fell, County Durham, on 22 July, 1865, died at his home in Hertfordshire on 27 December, 1955.

He was educated privately and at Durham College of Science, Newcastle-upon-Tyne. In 1883, his lifelong association with mines and mining began with an apprenticeship at the Hetton Collieries, County Durham; after 5 years, he was made under-manager of the Elemore Colliery. In 1891, he undertook the post of general manager of a colliery in Natal, South Africa, and was later employed by the Natal Government to investigate the oil shales of the Drakensberg Mountains. He returned to Great Britain in 1893, and became manager of the Seaton Delaval Collieries, Northumberland.

In 1902, he was chosen to be Professor of Mining at the recently founded University of Birmingham, where the degree of Master of Science was conferred on him. He relinquished the Chair in 1908, when he was appointed H.M. Chief Inspector of Mines. He was the first to hold this office. During his tenure, the Royal Commission of Mines elected him Chairman of the Committee of Experts appointed to investigate accidents in mine shafts, underground haulage, and falls in coal mines; he reported in 1909.

From 1905 to 1908, Sir Richard acted as an Expert Member on the Board of Directors of Collieries, and subsequently he sat on many official Committees concerned with conditions in, and improvements to, mines and quarries, particularly in the interests of safety.

From 1915 to 1916, he was Chairman of the Coal-mining Organization Committee, and from 1916 to 1920, Chief Technical Assistant to the Controller of Coal Mines and Vice-Chairman of the Coal Distribution Committee. He became a member, in 1917, both of the Coal Conservation Committee and of the Fuel Research Board. In 1919, he resigned from the office of Chief Inspector of Mines to devote himself to the work of the Imperial Mineral Resources Bureau, of which he was Chairman and United Kingdom representative until 1925, when the Bureau amalgamated with the Imperial Institute. Sir Richard continued to act as Chairman of the Mineral Bureau until 1935. A year previously he had been appointed Independent Chairman of the National Joint Conciliation Board for Road Motor Transport. He was also engaged, in private practice, as a consulting mining engineer.

Sir Richard was the author of a number of technical books, notably the five volumes of "Modern practice in mining" (1908–32), and he collaborated in the writing of others. He published his autobiography, "Men, Mines, and Memories" in 1942, and was a prolific contributor of Papers to learned societies and institutions.

He was created C.B. in 1912, and two years later, K.C.B. In 1917 he was made a Companion of the Order of St John of Jerusalem, and in 1918 the French Government made him a Chevalier of the Legion of Honour.

Sir Richard, who was elected Member in 1908, became a Member of Council in 1924. He was elected Vice-President in 1931, and was President of the Institution for the Session 1934–35.* He became a member of the Institution of Mining and Metallurgy in 1904, and was elected President in 1916. He was a Fellow of the Geological Society. In 1922 he was elected the first President of the Institution of Professional Civil Servants, and was re-elected annually up to the time of his death. He was an Honorary Member of the Institution of Mining Engineers, and of the Royal Institution of Chartered Surveyors.

Edith Rose Richards, whom he married in 1898, died in 1942. He is survived by one son and two daughters of the marriage.

ALBERT TULIP, M.Sc., who was born on 26 April, 1883, died on 9 November, 1955.

He studied at Durham University from 1902 to 1906. After obtaining his degree of Master of Science, he served as an articled pupil with Thomas Hanning of Newcastle, consulting engineer, and subsequently assisted Colonel J. M. Moncrieff on various dock and river works on the Tyne and the Tees.

In 1910 he became Assistant Engineer with the Port of London Authority under Sir Frederick Palmer and his successor Sir Cyril Kirkpatrick, and remained until 1924, when he was engaged with contractors and consulting engineers on various major engineering works. In 1929 he was appointed Assistant Engineer for Docks, London & North Eastern Railway, at Hull. He succeeded Mr J. A. Wickham as Chief Engineer for Docks, L.N.E.R., in 1930, and held that office until his retirement in 1947.

He was elected Member in 1928.

He was also a Member of the Institution of Mechanical Engineers, and a Fellow of the Geological Society.

He is survived by his wife.

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* Presidential Address: Min. Proc. Instn Civ. Engrs, vol. 239, p. 3 (1934–35, Pt 1).

# ANNUAL GENERAL MEETING

5 June, 1956

WILLIAM KELLY WALLACE, C.B.E., President, in the Chair

**The President** moved, and the Meeting agreed, that the Report of the Council which, as intimated in the May number of *Chartered Civil Engineer*, had been available to Members upon request to the Secretary, be taken as read.

The year under review had been particularly active and had witnessed the co-operation of the Institutions of Civil, of Mechanical, of Electrical, and of Chemical Engineers and the Institute of Physics in the formation of the British Nuclear Energy Conference for the promotion of knowledge on nuclear energy. The first Journal had been published and the next issue was due in July. The Journal was a very high-class publication, and it was an excellent thing that the Nuclear Energy Conference appeared to be meeting a need without the formation of a new Institution with corresponding calls on members for subscriptions.

The Institution had held 44 meetings to discuss various engineering works, compared with 35 in the previous Session, and even in such a short period the discussions at those meetings had brought out many improvements in technique which had been made and advances along the path towards automation.

The awards for Papers for the Session 1954–55 were shown in Appendix II of the Report and those for 1955–56 would be announced in the Spring.

During the year he had had the pleasure of attending the annual dinners of local associations and had been glad of the opportunities to meet Chairmen and Members of the associations, to whose work the Institution owed so much. The local associations were flourishing and the same could be said of the various overseas associations and the joint overseas groups.

An interesting development had occurred in Canada. A Joint Committee of Members of the Institution, the Toronto Branch of the Engineering Institute of Canada and the American Society of Civil Engineers had been set up to sponsor meetings in the Toronto area. It would be seen from the Report that the various Committees had been active; the work done by members of those and other Committees was a matter of satisfaction to the Council.

Turning to the accounts, he said it would be noticed that there was a deficit on the year's working of over £7,000. Rising costs of practically everything, and especially of printing and postage, had been a matter of great concern to the Council. The Report indicated that means for improving the situation would be placed before Members; in fact, that had already been done and all Corporate Members, both home and overseas, should have received particulars of proposed increases in the rates of subscriptions. The Council had been very reluctant to suggest the increases but had come to the conclusion that no other course was possible if the Institution were to continue as the parent body of engineering and to promote the objects for which it was intended. He hoped that those who had not already returned the voting papers would do so before the closing date at the beginning of September.

Referring to Item 5 of the Report, the Special General Meeting, he said that a

Committee at present revising the By-Laws was also considering the question raised by the Special General Meeting and a proposal would be made when the appropriate alterations to the By-Laws were submitted.

Item 9, referring to the Conference of the Representatives of the Engineering Societies of Western Europe and the United States of America, revealed that the fourth conference had been held in Copenhagen from 5 to 9 September, 1955. The more optimistic of them hoped that that body would lead to more standardized and, in some cases, higher codes of ethics among the various bodies; the British engineer, who tried to live up to the British code of ethics, were, at times, at a serious disadvantage.

It would be seen from item 15, dealing with the visits of Vice-Presidents to local associations, that visits had been made by Mr Gourley, Sir Arthur Whitaker, and Professor Pippard. The fourth Vice-President, Mr A. C. Hartley, had been abroad and had been unable to undertake visits of this nature. He hoped to do better in the future, but under present conditions it was difficult to control the necessity of some of his visits abroad.

Item 53 revealed that Cash at Bankers and in hand amounted to £46,777 at the close of the financial year; that might suggest that the Institution was affluent, but it was in fact due to the receipt of a substantial proportion of the current subscriptions during the first quarter of the present year. It was proposed to end the financial year on 31st December, the same date as the end of the subscription year, and that would even out the present large carry-forward.

The Roll revealed that there were now more than 21,000 Members, which was a sign that the profession was still steadily growing.

**Mr Rolt Hammond** referred to a suggestion which had been made three years ago regarding the possible publication of a comprehensive series of civil engineering abstracts at a subscription rate of about £2 per annum. Had there been any further development?

**The President** replied that the feasibility of publishing such abstracts was still being reviewed but the investigation was a lengthy business. If and when such a project was undertaken the cost would probably be considerably higher than the figure mentioned in the original suggestion.

There being no further questions, the **President's** motion for the reception and adoption of the Report was agreed to.

**The President** announced the following report of the Scrutineers on the ballot for the election of the Council for Session 1956–57.

# THE INSTITUTION OF CIVIL ENGINEERS
## COUNCIL 1956–1957

*President*

HAROLD JOHN FREDERICK GOURLEY, M.Eng.

*Vice-Presidents*

Sir (Frederick) Arthur Whitaker, K.C.B., M.Eng.
Professor Alfred John Sutton Pippard, M.B.E., D.Sc., F.R.S.
Arthur Clifford Hartley, C.B.E., B.Sc.
Sir Herbert (John Baptista) Manzoni, C.B.E.

*Other Members of Council*

Maurice Edward Adams, O.B.E.
Ronald Joseph Ashby, M.Sc.
John Frederick Allan Baker.
James Arthur Banks, O.B.E.
Arthur Borlase, T.D. (*South Wales & Monmouthshire*).
Professor William Fisher Cassie, Ph.D., M.S., F.R.S.E. (*Northern Counties*).
Frederick Earland Philip Clear, B.A., B.Eng. (*Ceylon*).
Walter Edmund Doran, O.B.E., B.A., B.A.I.
David Kerr Duff (*Edinburgh & East Scotland*).
Joseph Edgar Dumbleton (*Midlands*).
Johan Hendrik Durr, B.Sc. (*N. & S. Rhodesia*).
Sir George (Herbert) Fretwell, K.B.E., C.B.
Angus Anderson Fulton, B.Sc., F.R.S.E.
John Edward Harben, M.Eng. (*North Western*).
Harold John Boyer Harding, B.Sc.
Kenneth Palmer Humpidge, B.Sc. (*Colonies*)
Nathaniel Harvey Hunt (*India and Pakistan*)
Sir Claude (Cavendish) Inglis, C.I.E., M.A.I., F.R.S.
John Holmes Jellett, O.B.E., M.A.
Robert Ferguson Legget, M.Eng. (*Canada*).
William Linn (*Glasgow & West of Scotland*).
*Louis Francis Loder, C.B.E., M.C.E., D.Eng. (*Australia*).
Donald Stuart Gore Marchbanks, D.S.O., M.B.E. (*New Zealand*).
Robert McCreary, O.B.E., M.C., B.A., B.Sc. (*Northern Ireland*).
Sir George (Matthew) McNaughton, C.B., B.Sc.
Reginald William Mountain, B.Sc.
*Felix John Oliver, M.A. (*South Africa*).
*William Leonard Owen, C.B.E., M.Eng.
John Lawrence Paisley, M.B.E., M.Eng.
Thomas Angus Lyall Paton, B.Sc.
Adrian Benson Porter.
Joseph Rawlinson, C.B.E., M.Eng.
Brendan Francis Saurin, B.Sc.
George Edward Scott, O.B.E., V.D., M.Eng., B.Sc. (*South Western*).
Percy Edward Sleight, M.Eng. (*Southern*).
Hubert Shirley Smith, O.B.E., B.Sc.
Marcus George Russell Smith, M.B.E., B.Sc.
James Gilbert Taylor, C.B.E. (*Yorkshire*).
Charles Bruce Townend, C.B.E., B.Sc.
Sir Hubert (Edmund) Walker, C.B.E. (*Colonies*).
Godfrey Maurice Wheat (*Colonies*).
George Ambler Wilson, M.Eng.
Robert Meredydd Wynne-Edwards, D.S.O., O.B.E., M.C., M.A.

*Past Presidents to be appointed by the Council, November* 1956

* Newly elected.

**Mr D. A. de C. Bellamy** moved, **Mr C. M. Sinclair** seconded, and the meeting agreed that thanks be accorded to the Scrutineers and that the ballot papers be destroyed.

**Mr H. M. Bostandji**, on behalf of the Scrutineers, said that there had been 10,416 papers issued; 2,341 had been returned; and 55 of those had been invalid. It was welcome to report that there had been an increase of nearly 100 over the previous year in the number of papers returned.

**Mr H. S. Keep** moved, **Dr T. P. O'Sullivan** seconded, and the meeting carried a resolution that Mr J. A. Johnston, Member, be re-appointed Honorary Auditor for the current financial year; and that Mr R. T. M. McPhail be appointed the professional Auditor in place of Sir Alan Rae Smith, who had retired, for the current financial year.

**Mr H. Ridehalgh** moved, **Mr G. C. G. Beavan** seconded, and the meeting carried with acclamation a vote of thanks to the President for his conduct of the business as Chairman of the meeting.

**The President** acknowledged the vote of thanks and the meeting then terminated.

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## ADVERTISEMENT



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